Growth and Yield of Black Spruce, *Picea mariana* (Mill.) B.S.P., in Alaska

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Abstract

Black spruce, *Picea mariana* (Mill.) B.S.P., is largely overlooked in Alaska because of its small size and slow growth. Growth and yield information is therefore limited or nonexistent. Presented here are the first polymorphic site index (height-age) curves and height-diameter functions for predicting height and volume for Alaska black spruce. Models are accurate for trees up to 50 feet in height and 8 inches DBH. Predicted stem volumes range from 0.006 ft^3 to 21.8 ft^3 for trees between 0.5 and 11.5 inches DBH Sampled tree dimensions range from 5.5 to 78.0 feet tall and from 0.4 to 11.0 inches DBH. Sampled breast-height ages range from 49 to 257 years; average age-to-breast-height is 26 years. This research, although limited, also characterizes general stand-level structure and community composition for Alaska black spruce. 60 Permanent Sample Plots (PSPs) representing 20 stands were established throughout the Tanana Valley, with stand inventory conducted according to a consistent protocol. Stand densities range from 137 to 2,907 trees per acre; stand volumes ranged from 8 to 2,507 ft^3 per acre. Stand density index values range from 6 to 453. Periodic remeasurement of PSPs will yield valuable information about stand evolution and community type change.

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1 Introduction

The uniqueness of forests demands that information specific to their makeup be crafted and refined for use in sound management (Davis et al. 2001). Alaska's boreal forests are valued as sources of wilderness, recreation, and renewable raw material. They are also the foundation of a northern ecology in which the importance of wildland fire dynamics and the cycling and storage of carbon are beginning to be understood. Before investment decisions can be made, the potential of this forest must first be determined so that its productive, protective, and social functions may be fulfilled (Matthews 1989). This research addresses essential growth and yield tools specific to tree species in Alaska as a basis for any facet of forest management. This idea is not new, as Hatcher (1963) states:

For forest management to advance … a knowledge of yield potentials, growth rates, age structure, species composition, stand development, and regeneration habits must be acquired.

Black spruce, *Picea mariana* (Mill) B.S.P., is the most abundant tree species in Alaska (Zasada and Packee 1995). Its commercial value in the state is not debatable due to a dearth of productivity data for pure and mixed-species black spruce stands. This has frustrated efforts to make accurate resource assessments and to coordinate management and ecological research. More than 2,000 reports on black spruce ecosystems have been published in Canada and the United States (Krestov et al. 2000) but only a fraction have originated in Alaska, and none of these specifically address black spruce growth and yield. No site index curves, individual tree volume tables, or height-diameter relationships have been published for this species; hence, estimates of wood fiber potential are also nonexistent. Data for white spruce are commonly and incorrectly used as a surrogate for black spruce individual tree volumes and site index curves (Packee 2003). Stand volumes for white spruce are assumed to equal those for black spruce. Stand and community type descriptions for Alaska are also limited.

1.1 *RESEARCH OBJECTIVES*

This research provides a basis for understanding how black spruce grows in Alaska because it quantifies growth in a variety of ways. One major goal is the development of site index (height-age) curves and height-diameter equations to estimate site productivity and predict individual-tree heights and volumes, as well as the compilation of tree form, taper, and age-to-breast-height information. The second major goal is to describe black spruce stands in the Tanana Valley and adjacent areas using mensurational, physiographic, and vegetation data obtained from the establishment of permanent sample plots. These data will be used to summarize and compare stand diameters, stand heights, and stand densities across the Tanana Valley, and to describe vegetation community types and soil characteristics.

1.2 *STUDY AREA*

1.2.1 Physiographic Setting

The boreal forest, also known as the subarctic (Oechel and Lawrence 1985) or taiga (Hare 1954), is the largest biome — major life zone of interrelated flora and fauna — in North America. It covers nearly 30% of the North American continent north of Mexico, spanning 10° of latitude in places (Pojar 1996). It is found south of 49°N in Minnesota and Wisconsin, and north of the Arctic Circle, which is located at approximately 66°N. In Alaska, the northern border of the boreal forest occurs on the southern slopes of the Brooks Range; northern slopes of the Chugach and Wrangell mountains make up the southern edge (Lutz 1956, Zasada and Packee 1995). This continental region is known in Alaska as the Interior (Lutz 1956), and is a blend of the main boreal forest in the southerly regions and open boreal woodlands of the north (Oechel and Lawrence 1985).

Most of the sampling for this research was done in the Tanana Valley, a part of the Eastern Interior Alaska (EIA) zone within the Intermountain Plateau Region of interior Alaska (Zasada and Packee 1995). This region is bounded on the south by the Denali fault system, on the west by the lower Tanana and Kuskokwim rivers, and on the north and east by the Northway-Tanacross lowlands and Yukon-Tanana uplands (Foster et al. 1994). The Intermountain Plateau Region and EIA zone correspond, respectively, to the Intermontane Boreal Ecoregion and

Tanana-Kuskokwim and Yukon-Tanana Uplands zones defined by Nowacki et al. (2001). Additional sampling occurred in the Susitna-Matanuska Valley (SMV7) and Kenai-Alaska Peninsula (KAP) zones encompassed by the Pacific Mountain System (Zasada and Packee 1995). The Pacific Mountain System, SMV7, and KAP zones correspond, respectively, to the Alaska Range Transition Ecoregion and the Alaska Range and Cook Inlet Basin zones defined by Nowacki et al. (2001). Figure 1.1 illustrates the general physiographic setting for this research (map created by the author).

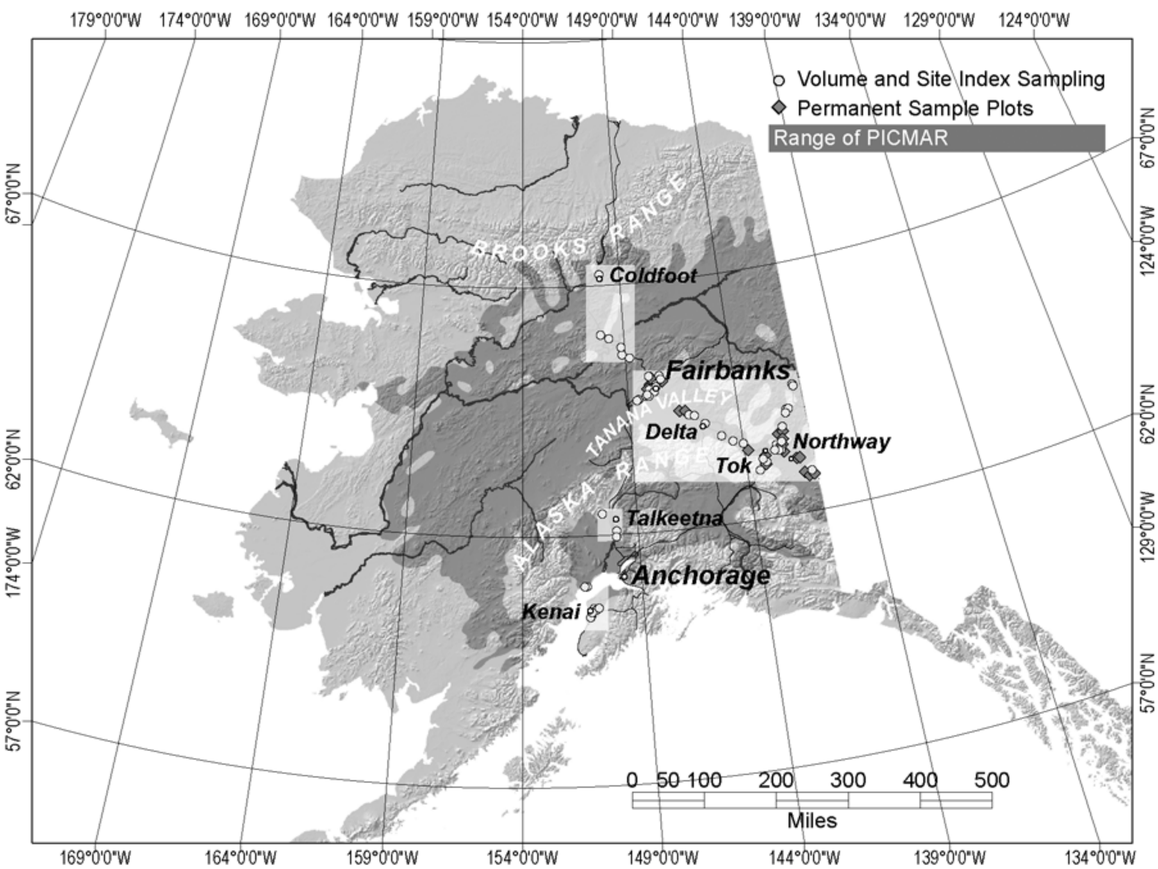

Figure 1.1. General physiographic setting.

1.2.2 Geographic Landforms, Soils, and Vegetation

Parts of the eastern Interior and most of the Southcentral and Kenai Peninsula regions were glaciated. Streams in both regions feature extensive outwash from alpine and piedmont glaciers in the Alaska Range, and moraines are readily visible in many valleys (Rieger et al. 1979). Except for its upper reaches, much of the Tanana Valley was not ice-covered during the

Pleistocene era but was nearly surrounded by glaciers from the Brooks Range, the Alaska Range, and western Canada. Bedrock material is mostly schist with granitic intrusives (Zasada and Packee 1995) that weathers relatively easily to form blocky talus. Soil parent materials include Aeolian (Giudetti-Schaefer 2002), residual, glacio-fluvial, morainal, and lacustrine (deposits from Quaternary lakes once dammed by ice).

It is difficult to determine the geologic history of this area (Foster et al. 1994) due to metamorphism and a dearth of fossils. Loess deposits and sand dunes, formed by material transported from Quaternary floodplains, are common and can be as much as 200 feet thick (Péwé 1970). One such deposit near Tok was recently analyzed for tephra layers that would indicate evidence of past volcanic activity. Tephra layers, alternated with organic-rich soil, loess, sand, and gravel, provided evidence for a series of 10 eruptions. The surface tephra, the White River Ash, was deposited almost 1,900 years ago and is common throughout extreme eastern interior Alaska. The deepest tephra was deposited 649,000 years ago (Mount Drum origin) and immediately above this is a 300,000-year discontinuity; above this are an additional eight tephras, some of which are also believed to be of Mount Drum origin (Giudetti-Schaefer 2002).

Permafrost is defined as ground where soil temperature consistently remains below 32°F for 2 or more years (Viereck et al. 1992). Permafrost is discontinuous in the Tanana and upper Yukon River drainages and absent on the Kenai Peninsula (Zasada and Packee 1995). Regardless of permafrost, soil temperatures are cold throughout the region; soils are gelid or cryic. A soil temperature of approximately 37°F has obvious negative implications for the rate of plant growth. Many investigators have noticed a distinct relationship between the location and depth of permafrost and the composition of surface vegetation communities, and that vegetation itself influences the depth of the active, or seasonally thawed, layer (Larsen 1980).

Regional vegetation includes heavily timbered bottomlands and slopes as well as alpine tundra (Péwé 1970). Lowland soils shallow over permafrost support black spruce and tamarack (*Larix laricina* [Du Roi] K. Koch), but upland soils deep over permafrost can support balsam poplar (*Populus balsamifera* L. spp. *balsamifera*), paper birch (*Betula neoalaskana* Sarg.), and white spruce (*Picea glauca* [Moench] Voss) (USDA-NRCS 2004). South of the Alaska Range, in the Turnagain Arm area and on the Kenai Peninsula, this list also includes mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.) and Sitka spruce (*Picea sitchensis* [Bong.] Carr).

1.3 SILVICS OF BLACK SPRUCE

1.3.1 Range and Distribution

Approximately 35 species of spruce occur worldwide in the northern temperate regions of North America, Mexico, and Eurasia (Taylor 2004). *Picea* probably originated in northeast Asia, and may have reached North America through a series of eastward migrations (Nienstaedt and Teich 1972) and mutations of the Japanese Yezo spruce, *P. jezoensis* Carr. (Wright 1955). Black spruce is thought to be a radiant from Northern Beringia that reached the Mississippi basin and the Atlantic coast. It survived the Illinoian and Wisconsin glaciations in refugia south of the ice and in the unglaciated Yukon River Valley (Halliday and Brown 1943).

A strong relation between black spruce and Serbian spruce (*P. omorika* [Panèiæ] Purkyne) has been suggested (Youngblood and Safford 2004); Nienstaedt and Teich (1972) state that this link formed when *P. mariana* first separated from *P. glauca*, possibly reaching North America during the Cretaceous prior to the separation of the continents. The lack of a complete North American fossil record for the period between the Pleistocene and the Cretaceous precludes the formation of a definitive history of spruces on this continent.

Growing at elevations ranging from sea level to 5,000 feet (Groot and Horton 1994), black spruce is one of seven spruce species native to North America (Lariault 1989), and one of three coniferous tree species comprising the extensive spruce-hardwood forests of interior Alaska (Viereck and Little 1972). Black spruce and white spruce have similar ranges, but black spruce occupies the greater proportion of land area within these ranges (Schultz 1969).

The eastern limit of black spruce follows the Atlantic coastline from northern Massachusetts to Labrador. The southern limit in the U.S. stretches westward from disjunct populations in New Jersey, Connecticut, Pennsylvania, and the Lake States, and continues westward across the Yukon and Alaska to the Bering Sea on Alaska’s west coast (Sargent 1933, Eyre 1980, Viereck 1980). In Canada, black spruce is abundant in Saskatchewan and northern Manitoba and attains its largest size in those provinces (Sargent 1933). It also occurs in Alberta in the eastern foothills of the Rocky Mountains and in central British Columbia (Viereck and Johnston 1990). The northern and western limits alternate with balsam poplar, tamarack, and white spruce at the latitudinal limits of trees in Canada and Alaska (Lariault 1989, Viereck and Johnston 1990). In eastern Canada, the northern limit is the Ungava Peninsula in Quebec and the southern shore of Hudson Bay in Ontario (Millar 1936). The delta of the MacKenzie River on the

Beaufort Sea forms the northern limit in western Canada. In Alaska, the northern boundary occurs south of the northern limit of trees commonly formed by balsam poplar and white spruce (Hustich 1953, Hare 1954, Eyre 1980). Figure 1.2 (Little Jr. 1971) illustrates the range of black spruce.

Figure 1.2. Range of black spruce.

1.3.2 Soils

Spruces in general are intolerant of xeric sites but can thrive on slightly acidic and moist, well drained soils (Youngblood and Safford 2004). Black spruce does not appear to suffer water stress from saturated soils, but it is sensitive to drought and low water potentials caused by lack of water or frozen soils (Oechel and Lawrence 1985). It is reportedly most productive on moist, well-drained alluvial bottoms or peaty soils containing large amounts of decayed woody material (Millar 1936). Pure stands of black spruce are common in wetlands, defined as areas with annual flooding, hydric soil, and hydrophytic vegetation (Brady and Weil 1999). A peatland is a type of wetland that features low soil temperatures, low nutrient availability (Wang and Macdonald 1993), and permafrost close to the soil surface (Lutz 1956). Black spruce stands in peatlands can be stunted, open, and pure or mixed with tamarack (Wang and Macdonald 1993); however, we have discovered many extremely dense stands growing on peatlands in interior Alaska. Black spruce is one of the few trees that can tolerate such conditions (Pulling 1918) and can even be a pioneer on floating mats of vegetation extending into boggy ponds (Harlow and Harrar 1968).

Black spruce is also found in upland areas of well-drained, mineral soils (Wang and Macdonald 1993) commonly occupied by white spruce (Lutz 1956). Coarse sand (Vincent 1965), and gravel (More and White 2002) can support pure stands; Viereck and Johnston (1990) also reported its growth on Tanana Valley loess deposits, on old river terraces, and in mixed stands on shallow, young mineral soils. Balsam poplar, quaking aspen (*Populus tremuloides* Michx.), and white spruce commonly, but not everywhere, overtop black spruce (Wang and Macdonald 1993). The first 30 miles of the Taylor Highway, near Tok in east-central Alaska, pass through rolling uplands and what is arguably the largest pure stand of black spruce in the state. Much of this area burned during the summer of 2004.

Muhs et al. (2001) report that summer temperatures in interior Alaska were as much as 3° to 4°C warmer during the time between the Wisconsin and Illinoian glaciations. Depending on moisture availability, these warmer conditions could have supported biomes ranging from cool steppe to boreal forest. *Picea* and *Betula* fossils found within stratigraphic units dating from the last interglacial indicate a boreal forest very similar to the present. This suggests that the boreal forest may have been much more extensive that it is today, even extending into higher-elevation areas now covered by tundra.

1.4 DENDROLOGICAL CHARACTERISTICS

1.4.1 Physical Features

Form of black spruce is typical of that of the spruces; that is, generally conical in shape (Youngblood and Safford 2004) with a tapering trunk that is often buttressed at the base. However, black spruce can adjust its physiology or growth form to inhabit a very wide range of site conditions. Arborescent form is symmetrical, but in more exposed areas, windblown snow and ice-tree interactions defoliate portions of stems that protrude above the snowpack, resulting in asymmetrical crowns. Heavy frosts can kill vegetative buds and cause apical dominance to transfer from leaders to lateral shoots (Pereg and Payette 1998). At high elevations, black spruce trees grow as prostrate shrubs known as krummholz (More and White 2002).

Black spruce tree size varies widely depending on location. Vincent (1965) reported average dimensions of 24 to 40 feet in height and 5 inches DBH in eastern Canada. Rangewide, in unmanaged stands on better sites, heights typically range from 45 to 65 feet and diameters from 6 to 12 inches (Sargent 1933). Maximum sizes are 90 to 100 feet in height and 18 to 36 inches DBH, but shallow roots usually inhibit attainment of such large size (Pulling 1918). The smallest mature, single-stem specimens are less than 10 feet tall and less than 1 inch DBH (Viereck and Johnston 1990). The biggest black spruce tree in the contiguous United States is in Wisconsin; it is 78.7 feet tall and 19.7 inches DBH (American Forests 2003).

Tight clusters of leaves and small, pendulous branches are distinctive characteristics (More and White 2002). Open grown trees retain live branches to ground level (Youngblood and Safford 2004); natural pruning occurs only in extremely dense stands. New twigs are pale green and coated with a pale pubescence; color changes to pale cinnamon during the first winter. Hairs are black on older twigs (Millar 1936). Bark thickness ranges from 0.125 to 0.5 inch (Vincent 1965). Bark scales are thin and reddish-brown to grayish-brown (Youngblood and Safford 2004). Leaves are blue-green, stiff, needle-shaped, and four-sided, with whitish lines (stomata) delineating the sides. Needle length ranges from 0.25 to 0.5 inch but can be as long as 1 inch under optimal (greenhouse) conditions (Millar 1936). Drought does not hinder needle length in black spruce as it does for other conifers sharing its range (Bakuzis and Hansen 1965).

The onset of annual growth varies considerably throughout the range of black spruce (Vincent 1965). Although photosynthetic rates are lower in conifers than in hardwoods, the photosynthetic period for black spruce (and for evergreen species in general) lasts a month longer than for deciduous associates. Needles can persist for more than 15 years on branches and allow the tree to maximize carbon and nutrient investments made in leaf production. In response to nutrient limitation, black spruce may maintain needles for as long as 13 years; photosynthetic activity may still be as much as 40% of the maximum rate (Oechel and Lawrence 1985).

The species is monoecious; male strobili may be yellow, purple, or crimson, and are ovoid and pendant. Female strobili are erect, cylindrical, and similarly colored (Youngblood and Safford 2004). Appearing in late May in the southern areas of its range and 1 to 2 weeks later in the northern portions (Uchytil 1991), the larger pistillate flowers occupy the upper crown while staminate flowers are more common on terminal branchlets at mid-height.

Cones are semiserotinous, ovate to spherical in shape, and are 0.75 to 1.25 inches long. Cones appear as early as 10 to 25 years of age. Good cone crops are produced every 2 to 6 years until senescence; seldom is there a complete crop failure (Vincent 1965). Unripe cones are green and turn bluish-purple when ripe. Older cones are reddish-brown to gray. Single cones or pairs of cones are suspended on branches from short, twisted stalks. Cones open partially and begin to release ripe seeds in mid-September, starting at the top of the cone and proceeding downward (Millar 1936, Tessier 1954). They remain partially open and release seed at a consistent rate throughout the following seasons (Place 1950); this guarantees a consistent seed supply (Tessier 1954). Cone scales are bonded together with resin that melts at 122°F and allows the cone to open fully (Thomas and Wein 1985) and assure a seed release following fire.

Seeds are dark brownish black and almost completely enclosed by rust-colored wings 0.25 inch long (Millar 1936). They are the smallest seeds produced by any North American spruce (Viereck and Johnston 1990) and average in length from 0.1 to 0.2 inch and number between 335,000 (Youngblood and Safford 2004) and 1,111,740 per pound depending on site and cone size (Vincent 1965). Toumey and Korstian (1931) ranked black spruce, with an average of 544,000 seeds per pound, second only to paper birch, with 711,680 seeds per pound.

1.4.2 Wood

The wood of black spruce is relatively soft, pale yellow, and straight-grained; growth rings are narrow (Viereck and Little 1972). In eastern North America, black, white, and red spruce (*Picea rubens* Sarg.) are sufficiently similar in wood characteristics that they are marketed together as “eastern spruce.” Wood shrinks moderately as it dries; it holds glue, paint, and nails well but resists impregnation by preservatives (Mullins and McKnight 1981).

The moderate density of black spruce wood makes it moderately strong. Specific gravity, a measure of wood density, is defined as the ratio of wood weight to the weight of an equal volume of water at 40°F. Specific gravity is considered to be an important physical characteristic because mechanical properties such as abrasion, hardness, heat value, resistance, and strength are closely correlated with wood density. Specific gravity also affects the amount of energy needed for milling and pulping. Packee et al. (1992) found that Alaska black spruce, with a breast-height, oven-dry specific gravity of 0.480, compares favorably with values for the species in Canada, and is only exceeded by a value of 0.514 for the Northwest Territories.

1.4.3 Longevity

Conifers can live a very long time in adverse conditions. This is best illustrated by bristlecone pine, *Pinus aristata* (Engelm.), where a positive correlation exists between moisture stress and tree longevity. Other characteristics of long-lived trees include sparse foliage, low radial growth rates, and low height-diameter ratios (Robichaud 1990). Barring catastrophic disturbance, decadence sets in at 100 to 120 years of age when black spruce trees begin to exhibit thin, ragged crowns and many dead branches (Tessier 1954). This species typically lives to a maximum age of 200 to 250 years, although trees 270 to 280 years old have been reported (Vincent 1965, Viereck and Johnston 1990). Millar (1936) reported a black spruce in Ontario with a stump diameter of 1 inch and a breast-height age of 120 years.

1.5 PHYSIOLOGICAL CHARACTERISTICS

1.5.1 Rooting Habit

Ice formation from freeze-thaw cycles in areas of permafrost can fracture roots (Oechel and Lawrence 1985). Black spruce has adapted to such growing conditions by developing a shallow, mat-like pedestal of roots (Hare 1954, Harlow and Harrar 1968) that turn downward only at their tips. This allows growth despite excessive moisture or permafrost; any taproot that forms remains short and underdeveloped (Schultz 1969). Instead of a taproot, numerous, smaller roots less than 1 inch in diameter extend straight down from the largest roots for only 1 to 2 feet (Millar 1936). Schultz (1969) measured the vertical root penetration of 40 black spruce trees that were 4 to 154 years of age, in 19 natural stands on the Upper Peninsula of Michigan. Roots of nearly 80% of the trees remained in the top 2 feet of soil. Average rooting depth was less than 18 inches on upland sites. Table 1.1 summarizes results of Schultz's study.

Table 1.1. Vertical root penetration by black spruce.

Maximum Depth of Root Penetration	Number of Roots Observed		Number of Trees
	Tap Roots	Sinker Roots	
0 - 12 inches	6	18	6
12 - 24 inches	10	51	22
24 - 36 inches	5	14	8
36 - 48 inches	0	4	4
Total	21	87	40

Horizontal rooting occurs regardless of tree age, soil bulk density, or soil texture (LeBarron 1945, Schultz 1969). Uniformly shallow rooting habits are reported in black spruce growing on boggy organic soils and coarse, podzolized sands in Ontario as well as on loamy upland soils in the Alberta foothills (Vincent 1965). Shallow roots combined with cryic mounding ("frost heaving") at the soil surface cause trees to lean or fall. A "drunken forest" (Strang 1973) appearance is common in old, multi-cohort stands growing on hummocky terrain (Zoltai 1975).

1.5.2 Hybridization

The extensive overlap of the ranges of black and white spruce (Mann et al. 1995) has led many to presume natural hybridization occurs between the two species, but the flowering and budding process of black spruce occurs 1 to 2 weeks later than that of white spruce. By mid-June, black spruce buds are open, but white spruce has already flowered and produced new leaves (Millar 1936). Despite the difference in timing, however, a natural black spruce/white spruce hybrid has been reported in Minnesota (Little and Pauley 1958), yet remains independently unverified (Taylor 2004). Black spruce/red spruce hybrids are common in eastern Canada, where ranges overlap (Wright 1955). Natural introgression of black spruce into stands of red spruce in New Brunswick has resulted in larger hybrids (Youngblood and Safford 2004).

1.5.3 Competitive Ability

Black spruce seedlings can develop in the understory with as little as 10% of full sunlight (Wang and Macdonald 1993); however, survival and growth are more vigorous in open stands (Viereck and Johnston 1990). The species also tolerates intense rooting zone competition in soils shallow over permafrost (Hare 1954). Bakuzis and Hansen (1965) rank black spruce third in shade tolerance after red spruce and balsam fir (*Abies balsamea* (L.) P. Mill.) in New Brunswick. They also report that black spruce survives intense shade and root competition and responds to release slightly better than white spruce, ranking it as “high mid-tolerant.” Viereck and Johnston (1990) classify black spruce as shade tolerant, but less so than balsam fir and northern white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.).

On better-drained, loamy soils in Alaska, white spruce, birch, and alder (*Alnus* spp.) are main competitors. Following fire, black spruce is a common pioneer species on newly exposed mineral soil or ash-rich organics and temporarily shares growing space with other, faster-growing species such as willow, (*Salix* spp.), aspen, and birch. Black spruce is successful where fires are frequent and patchy due to its persistent, semiserotinous cones and early sexual maturity (Oechel and Lawrence 1985). Reproduction is best where fire has consumed the upper layer of organic and humic material. Black spruce can locally dominate uplands after fire; however, Larsen (1980) contends that the most extensive stands occur in poorly drained areas where competition from tree species other than tamarack is weak (Viereck and Johnston 1990).

1.5.4 Reproduction from Seed

Black spruce is a prolific seeder (Viereck and Johnston 1990). Uchytil (1991) reports an annual seedfall of 344,000 seeds per acre from mature trees in central Alaska. Despite the great quantity produced, seeds travel a distance of approximately twice the height of dominant trees (Morneau and Payettte 1989). Seeds must germinate quickly because due to a short growing season and a drop in viability 10 to 16 months after leaving cones (Fraser 1976). Seeds within cones have a “consistent vitality” (Tessier 1954) that persists as long as 8 (Morneau and Payettte 1989) to 15 years (Harlow and Harrar 1968). 50% or more of the seeds remaining in cones 1 year after ripening are viable; 5 years later, 15% are viable (Wilton 1963).

Germination can occur on freshly fallen or slightly decayed plant materials (Troth et al. 1976, Viereck et al. 1992). Moss, common in the understory of black spruce stands, can be a good growing medium (Lutz 1956). *Sphagnum* spp. and *Polytrichum* spp. maintain favorable germination conditions because they can transport water internally through their stem structures and alter their leaf orientation to resist dessication (Oechel and Lawrence 1985). However, low soil temperatures under moss stall seedling growth even during warm periods (Dang and Lieffers 1989). Physiological drought or “winter kill” can occur anytime regardless of air temperatures and light levels sufficient for photosynthesis; needles continue to transpire, dry out, and die from lack of water while roots remain at temperatures below freezing (Larsen 1980). Sands with a moss understory also experience a unique type of nutrient stress. Feathermosses act as nutrient “sponges” that immobilize nitrogenous and ionic nutrients from anything that falls on the moss surface. Additionally, *Polytrichum* spp. can mobilize water and nutrients from the soil mineral layer (Oechel and Lawrence 1985).

Mineral soil exposed during fires of moderate to high intensity provides the best seedbed, but can become so hot in direct sunlight that seeds and/or seedlings cannot survive. Black spruce has developed strategies to survive such inhospitable growing conditions. Cones left unopened by low-intensity fires will open later and release seeds (Bakuzis and Hansen 1965). Lutz (1956) reported, “many … black spruce [seedlings] on burned-over areas originate from seeds present in unopened cones persisting on the trees at the time of the fire.” Seedlings can also delay emergence from soil until better conditions exist (Thomas and Wein 1985).

Black spruce seedlings can range from 4,000 to 13,000 stems per acre, as Place (1950) found in New Brunswick. In Alaska, Lutz (1956) reported 5,000 stems per acre at least 1 inch in diameter in a 30-year-old stand and 2,000 to 3,000 stems per acre in 100-year-old stands. Nearly 300 of the trees in these older stands were at least 5 inches DBH. Seedling survival depends on outgrowing competing plants before the moss layer becomes too thick, as can happen quickly in the absence of thick shrubs (Vincent 1965). Existing vegetation can provide valuable shelter (Chrosciewicz 1976) except where rapidly spreading species such as *Ledum* spp. and leatherleaf (*Chamaedaphne calyculata* (L.) Moench) dominate the understory (Tessier 1954); *Ledum* spp. in particular may be allelopathic (Inderjit and Mallik 1996).

1.5.5 Vegetative Reproduction

Black spruce responds to water table fluctuations and thickening soil organic layers by forming small adventitious roots above the root collar and the wettest soil horizons (Millar 1936). Layering is an important adaptation to rigorous habitat conditions and an efficient means of vegetative reproduction in open-grown, poorly stocked stands (Larsen 1980, Eyre 1980, Damman and Johnston 1980, Viereck and Johnston 1990). It occurs at any age, and its frequency increases with latitude and altitude (Bakuzis and Hansen 1965).

Little is known about the number of layers that can be grown and discarded over a tree’s life span (Vincent 1965). One Minnesota black spruce, 5 inches in diameter and approximately

140 years old, had five layers of roots extending from the main stem. The lowest layers were dead or dying, but the roots on the top layer were actively growing. The distance from lowest to uppermost layers measured 20 inches (LeBarron 1945). Laberge et al. (2000) found an 1,800-year-old black spruce clone with more than 80 layers growing near treeline in Quebec. It is unclear if layered branches ever become independent of the parent (Oechel and Lawrence 1985); however, clones formed in this manner may persist for centuries (Laberge et al. 2000).

1.5.6 Growth Inhibitors

Black spruce suffers from attacks by insects, parasites, and pathogens. This discussion is limited to those that attack black spruce in the western and northwestern parts of its range.

Choristoneura fumiferana (Clemens), the spruce budworm, is the most important conifer defoliator in eastern North America (Johnson and Lyon 1991). High budworm populations are linked to overmaturity in trees. Minor damage occurs on black spruce because its buds open later than those of other trees in its range (Bakuzis and Hansen 1965). The budworm has attacked white spruce in Alaska. *Adelges laricis* (Vallot) and *Pineus pinifoliae* (Fitch) are adelgids that form needle galls on black spruce, a primary host of overwintering instars (Johnson and Lyon 1991). *Dendroctonous rufipennis* (Kirby), the spruce bark beetle, attacks all spruce species within its transcontinental range in North America (Holsten et al. 1989) and has attacked all three spruce species native to Alaska.

Less than 20 pathogens attack black spruce. *Rhizosphaera kalkhoffii* Bubak causes premature death and casting of needles; defoliation only slightly affects needles of black spruce. *Herpotrichia juniperi* Petrak and *Sirococcus conigenus* (DC.) P. Cannon & Minter cause needle blights on black spruce buried beneath snow, killing branches and twigs by binding them together with feltlike mycelial mats. *Chrysomyxa arctostaphyli* Dietel causes a rust known as “yellow witches’-broom.” Brooms can reach diameters of 6 feet; severely afflicted spruces can have dead or broken tops, grow slowly, and die prematurely. Others in the genus include *C. ledi* (de Bary), which attacks needles; *C. pirolata* G. Wint. in Rabenh., which kills seeds and causes premature opening of cones; and *C. woroninii* Tranz., which infects opening buds and causes shoot blight.

Inonotus circinatus (Fr.) R.L. Gilbertson and *I. tomentosus* (Fr.:Fr.) S. Teng are white rots that cause “stand-opening disease.” Decay spreads outward from the original hosts and infects the roots and lower stems of trees via the root system, and results in mushy wood, growth suppression, and blowdown in trees older than 50 years. Sizes of stand openings can reach more than 0.5 acres. *Phaeolus schweinitzii* (Fr.:fr.) Pat. infects roots and the lower stems of black spruce of any age. Wood turns dark brown and cracks into cube-like pieces (Sinclair et al. 1987). *Phellinus pini* (Thore:Fr.) A. Ames causes heart rot and cankers and has been reported on black spruce in British Columbia (Natural Resources Canada 2004). *Leucostoma kunzei* (Fr.:Fr.) Munk, *Cenangium ferruginosum* Fr.:fr., and *Ascocalyx abietina* (Lagerberg) Schlapfer cause cankers and twig dieback that deforms or kills lower branches and stems. Evidence of infection includes a clear, amber resin that hardens into a white crust (Sinclair et al. 1987).

Bog Labrador tea (*Ledum groenlandicum* Oeder) and marsh Labrador tea (*Ledum palustre* L. spp. *decumbens* [Ait.] Hultén) are perennial ericaceous shrubs that may leach water-soluble phenolics in to the organic soil horizons in their immediate locality. Growth measurements and foliar nutrient analyses of trees made at Ontario sites with and without *Ledum* revealed these phenolics may slow the growth of black spruce (Inderjit and Mallik 1996).

COMMUNITY CHARACTERISTICS

1.5.7 Tree Associates

Black spruce appears as a dominant or codominant in 30 cover types and subtypes defined by Eyre (1980) throughout the United States and Canada. A “dominant” species must comprise a minimum of 20% of the basal area and define the cover type. In a “pure” stand, one species comprises at least 80% of the basal area. Black spruce is dominant in 4 types and 8 subtypes and an associate in 14 types and 4 subtypes; its dominance reflects an increase in prevalence of fire and cold, peaty substrates (Rowe and Scotter 1973). Tables 1.2 and 1.3, respectively, summarize eastern and western cover types where black spruce is dominant or an associate.

Latitudinal distribution is uniform, but latitudinal changes from northern or southern borders result in predictable and equivalent changes in community type (Larsen 1980) and a steep decline in the variety of associated tree species from east to west. Black spruce comprises 30% to 60% of the total tree cover in the southern portions of its range, but moving north and west, species drop out and the percentage of black spruce approaches 99% (Halliday and Brown 1943). Table 1.4 summarizes transcontinental cover types (after Eyre 1980). In each table, gray boxes in the leftmost column indicate cover types where black spruce is a dominant. In the rightmost column, boldface type highlights black spruce as an associate.

Table 1.2. Eastern cover types and tree associations that include black spruce.

EASTERN COVER TYPES		
Cover Type – SAF No.	Range	Tree Associates
Jack Pine – 1	New Brunswick to Northwest Territories; Lake States, N New England, NY	**Black spruce**, aspen (bigtooth, quaking), birch (paper), fir (balsam), maple (red), oak (bur, northern pin, red), pine (eastern white, red), poplar (balsam), spruce (white)
Black Spruce – 12	Transcontinental; to treeline in Canada; MN; NE U.S. (>2000′ elevation)	Ash (black), aspen (quaking), birch (paper), fir (balsam), maple (red), northern white-cedar, pine (jack), tamarack, spruce (red, white)
Black Spruce-Tamarack – 13	Maritime Provinces, Quebec, Ontario; Lake States	Alder (speckled), fir (balsam), northern white-cedar, willow
Red Spruce – 32	Maritime Provinces, Quebec, Ontario; New England, NY, southern Appalachians	**Black spruce**, ash (mountain), aspen (quaking), beech (American), birch (gray, paper, yellow), cherry (pin), fir (balsam, Fraser), hemlock (eastern), maple (red, striped, sugar), pine (eastern white, red), oak (northern red), yellow buckeye
Red Spruce-Balsam Fir – 33	Maritime Provinces, Quebec, Ontario; New England, NY, W VA	**Black spruce**, ash (black, white), aspen (bigtooth, quaking), beech (American), birch (gray), eastern hop-hornbeam, hemlock (eastern), northern white-cedar, maple (sugar), pine (eastern white), poplar (balsam), spruce (white), tamarack
Northern White-Cedar – 37	Quebec and Ontario; NY, New England, N Lake States	**Black spruce**, ash (black), aspen (bigtooth, quaking), birch (paper, yellow), fir (balsam), hemlock (eastern), maple (red), pine (eastern white), poplar (balsam), spruce (red, white), tamarack
Tamarack – 38	Maritimes to Alberta; NY, New England, Lake States	**Black spruce**, ash (black), aspen (quaking), fir (balsam), maple (red), northern white-cedar, spruce (white)
White Spruce – 107	Transcontinental to treeline; N New England; Maritimes	**Black spruce**, aspen (quaking), birch (paper, yellow), fir (balsam), maple (sugar), spruce (red)

Table 1.3. Western cover types and tree associations that include black spruce.

WESTERN COVER TYPES		
Cover Type – SAF No	Range	Tree Associates
White Spruce – 201	Transcontinental; to treeline in AK and Canada (boreal)	Black spruce, aspen (quaking), birch (paper), Douglas-fir, fir (balsam, subalpine), pine (jack, lodgepole)
White Spruce-Paper Birch – 202	W Canada and AK, Arctic Circle–Kenai Peninsula	Black spruce, aspen (quaking), fir (subalpine), pine (lodgepole)
Balsam Poplar – 203	Transcontinental; Canada and AK	Black spruce, birch (paper), spruce (white), tamarack
Black Spruce – 204	Transcontinental	Aspen (quaking), birch (paper), fir (balsam), pine (jack, lodgepole), spruce (white), tamarack
Englemann Spruce-Subalpine Fir – 206	W. U.S.; SW Canada	Black spruce, birch (paper), poplar (balsam)
Aspen - 217	Alaska to Atlantic Ocean; spans more than 47° of latitude	Black spruce, birch (paper), Douglas-fir, fir (subalpine, white), pine (lodgepole, ponderosa), poplar (balsam), spruce (Engelmann, white)
White Spruce-Aspen – 251	W and NW Canadian provinces; interior AK	Black spruce, birch (paper), fir (balsam), pine (lodgepole)
Paper Birch – 252	Canada (boreal); AK, Arctic Circle–Kenai Peninsula	Black spruce, aspen (quaking), pine (lodgepole), spruce (white)
Black Spruce-Paper Birch - 254	Interior AK; N Yukon	Aspen (quaking), spruce (white), tamarack

Table 1.4. Transcontinental communities that include black spruce.

TRANSCONTINENTAL COVER TYPES		
Cover Type – SAF No	Range	Tree Associates
Black Spruce – 12	Eastern: to treeline in Canada; MN; northeast U.S. (>2000′ elevation)	Ash (black), aspen (quaking), birch (paper), fir (balsam), maple (red), northern white-cedar, pine (jack), tamarack, spruce (red, white)
Black Spruce – 204	Western: Canada and AK	Aspen (quaking), birch (paper), fir (balsam), pine (jack, lodgepole), spruce (white), tamarack
White Spruce – 107	Eastern: to treeline; N New England and Maritimes	Black spruce, aspen (quaking), birch (paper, yellow), fir (balsam), maple (sugar), spruce (red)
White Spruce – 201	Western: to treeline in AK and Canada (boreal)	Black spruce, aspen (quaking), birch (paper), Douglas-fir, fir (balsam, subalpine), pine (jack, lodgepole)
Balsam Poplar – 203	Alaska to Atlantic Ocean	Black spruce, birch (paper), spruce (white), tamarack
Aspen – 217	Alaska to Atlantic Ocean; spans more than 47° of latitude	Black spruce, birch (paper), Douglas-fir, fir (subalpine, white), pine (lodgepole, ponderosa), poplar (balsam), spruce (Engelmann, white)
Paper Birch – 252	Western: Canada (boreal); AK, Arctic Circle–Kenai Peninsula	Black spruce, aspen (quaking), pine (lodgepole), spruce (white)

1.5.8 Understory Associates

Knowledge of understory vegetation is an important tool in forestry for assessing successional trends, regeneration possibilities, and site quality (Rowe 1956). Daubenmire (1952) developed a classification system based on potential (climax) vegetation communities for Washington and Idaho; (1977) expanded this idea in Montana. More recently, Peinado et al. (1998), DeVelice et al. (1999), Rivas-Martinez et al. (1999), and the British Columbia Ministry of Forests (Krestov et al. 2000, Klinka et al. 2002) have physiographically classified potential vegetation in the boreal region.

The floristic distribution of the boreal forest is relatively uniform and features a relatively low species diversity throughout its vast transcontinental area. However, Pojar (1996) asserts that biogeography causes the reduction in the number and type of species from east to west. Cordilleran and Beringian elements underlying the western boreal forest (defined as the region from Manitoba west through Alaska) are not present in the eastern boreal forest, which is underlain by the Canadian Shield.

Klinka et al. (2002) report the existence of more than 2,000 black spruce community studies, although little investigation has been made in even-aged, mid-seral stands. Viereck et al. (1992) summarize Alaska-specific vegetation classifications including work by Yarie (1983), who classified 40 forest communities of the upper Porcupine River drainage of interior Alaska. More recently, Gracz et al. (2004) described black spruce communities on the Kenai Peninsula. New community type descriptions for Alaska black spruce are currently being developed.[1]

1.5.9 Succession

Connell and Slayter (1977) define succession as the pattern of recovery that an ecological community undergoes in response to disturbance. Competition is the most important biological interaction in communities; how species respond to disturbance that varies widely in severity, scale, and timing is the essence of succession. Figure 1.3, as presented by Viereck (1989), illustrates the general successional position of black spruce relative to other tree species on the floodplain of the Tanana River in interior Alaska.

[1] Hollingsworth TN. Personal communication.

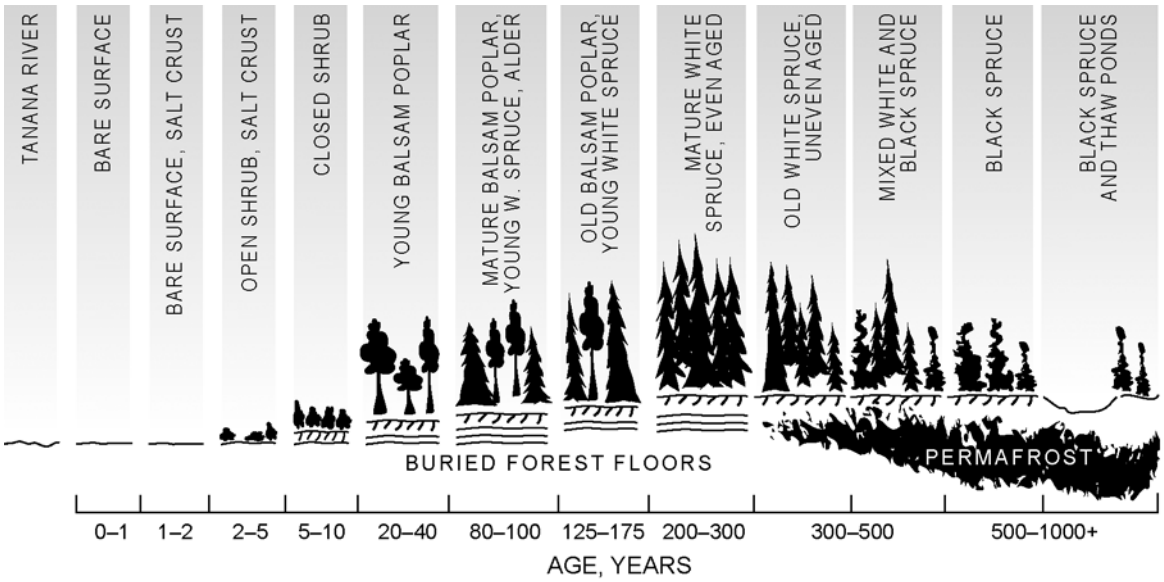

Figure 1.3. Tanana River floodplain forest succession.

The scope of the boreal region and its plant communities foster myriad pathways of succession. Successional patterns depend on the type and severity of disturbance as well as on the available seed source. The longest successional series of species occurs on newly developed floodplains (Oechel and Lawrence 1985). The Drury Hypothesis, cornerstone of ecological studies in Alaskan boreal forests for 25 years, states that permafrost development drives later successional phases of this series. However, Mann et al. (1995) assert that the exact time required for succession to proceed to black spruce is unknown, and the processes inherent in the transition to black spruce lack sound documentation. In support of this argument, Connell and Slayter (1977) assert that the decline in the availability of direct evidence from early to late successional stages makes it difficult to clearly see the mechanisms governing changes in species composition. The Drury Hypothesis may thus be an oversimplification (Mann et al. 1995).

Shaw et al. (2001) also assert that the Drury paradigm may not apply to all Alaska floodplains. By relating soil development to succession on floodplain and upland sites, they showed that soil development characteristics such as organic matter scouring and deposition, as well as salt crust dissolution and formation, explained significant negative correlations between site index and elevation at sites throughout interior and southcentral Alaska. They concluded that relatively uninterrupted soil development on upland sites might result in higher indices of productivity. In addition to being of questionable validity on floodplains, The Viereck-Drury models may also be inadequate for explaining growth and succession on moist, upland, non-floodplain sites.

1.5.10 Disturbance

Fire is considered the defining characteristic of black spruce cover types (Viereck and Johnston 1990). Black spruce is predisposed to burning; beard lichens, commonly of the genera *Bryoria* and *Usnea*, grow draped over branches that are themselves resinous and very flammable. This, combined with an understory of resinous shrubs such as *Ledum* spp., creates an environment favorable to intense fires (Lutz 1956). Fires of varying intensities can burn sections of forest or destroy entire stands (Auclair 1985), lower the permafrost table, and produce a relatively stable surface for tree growth for the next 80 to 100 years (Zoltai 1975).

Because of fire, most boreal forest types are transitional, with a trend toward spruce (Rowe 1956). In Alaska, intermediate successional stages can include white spruce, aspen, and birch (Eyre 1980), but black spruce is the only tree species that remains until fire destroys the community and the cycle begins again (Larsen 1980). Extensive, pure stands of black spruce tend to be of fire origin; on sites where it is well adapted, such stands are the product of centuries of succession (Vincent 1965). Where the prefire stand was pure, most studies show that no tree species replacement occurs (Morneau and Payettte 1989).

Black spruce reproduction is favored by severe fires that consume entire trees as well as the entire understory (Lutz 1956) and temporarily destroy competition (Bakuzis and Hansen 1965). Postfire recovery is characteristically rapid (Morneau and Payettte 1989). Groot and Horton (1994) state that natural stands younger than 160 years are essentially single-cohort because of the great release of seed from the many cones that fully open after fire. Seed falls onto newly exposed mineral soil (Vincent 1965), ash, or shallow humus. Soil surface-horizon temperatures of burned woodlands remain higher than those on unburned woodlands for as many as 25 years after fire and, thus, rates of primary productivity and nutrient cycling can increase dramatically (Auclair 1985). Depending on site type (Groot and Horton 1994), the structure of closed stands that have not burned for 100 years or more will proceed towards multi-cohort as seedlings fill in gaps left by dying trees. However, such stands are rare except on bogs and muskegs because fire is less frequent on lowlands than on uplands (Viereck and Johnston 1990).

1.5.11 Value and Use

Superior fiber quality makes black spruce one of the more desirable boreal forest tree species (Inderjit and Mallik 1996). Black spruce is the most commercially important conifer pulpwood species (Harlow and Harrar 1968) and one of the major timber crop species in eastern Canada (Krestov et al. 2000). The wood is used primarily for pulp and paper production because of the relative lack of color and freedom from resin (Millar 1936, Uchytil 1991). The slow growth of this species produces strong, durable, and fine-grained wood. Trees of sawtimber size have been used for mine timbers, cooperage, window sash, finish carpentry, musical sounding boards, lath, and boxes (Millar 1936). Containers, particularly those holding food, are ideal products because the wood is virtually odorless and tasteless, (Mullins and McKnight 1981). Black spruce needles contain volatile oils and are one of the richest natural sources of bornyl acetate, the base of perfume formulas having a “pine” odor (Vincent 1965).

Black spruce makes up for its relative lack of stature with a transcontinental range of pure or nearly pure stands that grow on a wide variety of site types. This species dominates the boreal landscape and plays a prominent role in northern forest ecosystem dynamics. Analysis of the height-age and height-diameter relationships (growth and yield) of black spruce, never done previously for the species in Alaska, justifies this research. Such basic quantitative information will provide essential tools for forest management and continued study of the fire cycle and carbon storage in the boreal forest.

2 Black Spruce Site Index

2.1 INTRODUCTION

Forest productivity information is essential to sound land management decisions, wildland fire behavior, and long-term ecological studies. Quantification and prediction of the response of trees to climatic, edaphic, and biotic factors is necessary so that the potential productivity of forest stands may be realized. Such information is limited or nonexistent for many Alaska tree species, especially black spruce.

Similar forest types grow on a variety of terrain, but productivity varies tremendously. Foresters use the term “site quality” to characterize forest stand productivity and express trees’ reaction to their environment (Belyea 1931). A good-quality site for one species may be poor for another (Clutter et al. 1992); “quality,” therefore, is species-specific (Chapman and Meyer 1949). Historical yield records and stand volume or height data are direct methods for quantifying site quality. Site quality may be indirectly estimated using relationships between vegetation, topographic, climatic, and edaphic characteristics.

2.1.1 Site Quality and Tree Height

Life depends on the basic factors of light, warmth, moisture, and nutrients (Rowe 1956). A tree grows, or accumulates height, based on its ability to compete for light, but the competitive advantage of height is eventually offset by greater maintenance costs and increased exposure to storm winds (King 1990). Generally, early growth is slow and increases to some maximal rate that gently tapers (Czarnowski 1961). Mature trees slowly cease to grow taller yet continue to grow in girth, suggesting “an evolutionary balance between the costs and benefits of stature” (King 1990). This phenomenon of growth resulting from opposition between the tendency toward unlimited increase and environmental resistance (Yin et al. 2003) is quantifiable. In Germany in 1824, Huber used a so-called “index method” to relate height to age in dominant trees (Cajander 1926); Roth (1916) made the earliest such attempts in North America. Site index is now considered a standardized (Haaglund 1981), quantitative, and thus objective method for reflecting environmental effects on tree height growth (Husch 1963). It is defined as the average height of mature (Carron 1968) dominant and codominant trees (Chapman and Meyer 1949) in pure, well-stocked, even-aged stands (Huang and Titus 1993), at an index age of 25, 50, or 100 years (Avery 1967). It is the most widely used means of estimating forest site productivity in North America (Payandeh 1974). Ideally, a height-based site index is independent of most stand history and management (Thrower et al. 1994). For most species, height depends less on stand density than do diameter, volume, or basal area, is virtually unaffected by competition between trees (Beaumont et al. 1999), and responds well to site quality differences (Chapman and Meyer 1949).

In addition to height, soil characteristics can provide especially stable assessments of productivity (Viereck and Johnston 1990). Forested sites may have soils that are deep or shallow, acidic or alkaline, wet or dry, peaty or sandy, rocky or mostly clay (Belyea 1931). Differences in soil moisture control the distribution of competition (Millar 1936) and have the greatest effect on site index across regions. However, while it is important to strengthen links between biophysical factors and site productivity, soil qualities such as clay content, nutrient levels, and temperature have different proportional effects on growth depending on soil type and tree species (Husch 1963), and can result in overly complex models if used as variables in a site index equation. Climatic and topographic variables often substitute for soil variables (Clutter et al. 1992).

2.1.2 Limitations of Site Index

Site index is not a good indicator of productivity in mixed-species stands due to a very weak relationship between height and age (Huang and Titus 1993). Measurement of "average height" is meaningless (Cajander 1926), and determining exact stand age is difficult because the curves magnify small age differences (Avery 1967). Site index curves provide little indication of other forms of productivity such as volume, because height is only one component of volume (Curtis 1964). Site index does not apply to newly cutover lands (Ung et al. 2001), to stands whose sampled trees were previously suppressed, or to stand development patterns that differ markedly from those depicted by the curves (Gevorkiantz 1957).

Estimating site index in young stands is difficult. Small calculation errors of early height growth skew estimations of future yields if young stands comprise a significant part of the stocking. The growth-intercept method (Avery and Burkhart 2002) attempts to estimate site index in young stands. A series of height measurements is taken from a specified distance above the ground, averaged, and substituted for the *height* variable in the site index equation (Nigh and Klinka 2001). However, short-term climate variations and competition can negatively affect early height growth and thus the accuracy of site index estimates made with this method.

Spatial and temporal factors can limit the applicability of site index curves. Wide-ranging species such as black spruce require region-specific curves (Page and van Nostrand 1971, Payandeh 1978, Viereck and Johnston 1990). Because the method assumes all trees to have been injury-free for the entire time they have been growing, site quality can appear inordinately poor if previously injured trees are included in the sample. However, detection of historic injury is not always possible, and injured trees are likely to be included in a forest inventory (Brickell 1968).

Site index shows the height development pattern that a tree can be expected to follow throughout the life of the stand (Clutter et al. 1992) but reveals little about complex ecological relationships that can exert aggregated influence on productivity (Curtis 1964). Different soil conditions, for example, can confound growth patterns and require "tailored" curves (Heger 1969). Carmean (1956) developed site index curves for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and was among the first to make special accommodation for soils. Zahner's (1962) work with loblolly pine (*P. taeda* L.) is another example.

This discussion lists a variety of limits to the universal applicability of the site index method of productivity estimation. However, the method's deficiencies for assessing productivity do not outweigh its operational importance (Ung et al. 2001) as a simple, numerical value that is easily measured and understood in forestry practice (Avery and Burkhart 2002).

2.2 DEVELOPMENT OF METHODOLOGY

2.2.1 Terms Used in Site Index

Quantitative site productivity assessment begins by ranking the competitive success of trees in a stand according to crown class. Bruce and Schumacher (1950) define four main crown classes. The dominant, or largest, trees grow in or above the main canopy level, receive full sunlight on their tops and at least on one side, and have the best-developed crowns. Codominants form the main canopy and receive direct light from above but little from the sides; their well-developed crowns are somewhat crowded by neighboring trees. Intermediate trees form the lower canopy; their small, crowded crowns receive little direct light from above and none from the sides. Suppressed trees receive no direct light from above or from the sides.

Sampling the "best" trees eliminates the influence of relative canopy position (Belyea 1931) and light (Robichaud 1990) as limiting factors. However, this method assumes that the entire stand is the same age (single-cohort), since crown class is difficult to determine in double- or multi-cohort stands. The assumption that a dominant or codominant tree has always remained so is valid unless the species of interest is shade tolerant or prone to windthrow, in which case crown class might vary throughout life of the tree (Clutter et al. 1992).

Reference age is based on the approximate age of maturity of the species (Bull 1931) and is the age used for graphical representation of site index equations; e.g., a tree with site index 80 and reference age 50 means the tree was 80 feet tall by the time it was 50 years old at breast height (4.5 feet). Breast-height age is more easily obtained and accurate than total age (age measured at the stump or root collar) because the former measurement is made after a tree is established and growing more predictably (Husch 1956). Reference age can be as low as 15 for planted red pine (Bull 1931) or 25 years for short-rotation coniferous plantations in Australia and the southeastern United States (Carron 1968), but typically ranges between 50 years for eastern species and 100 years for longer-lived western species (Chapman and Meyer 1949).

Reference age should be low enough for trees to have had the opportunity to fully develop, yet not so high that data become unavailable or the number of suitable sites is restricted (Carron 1968). Another caveat is that serious under- or over-prediction of site index and future stand yields can occur if reference age is high and the trees of interest grow on soils different from those depicted in the original curves, (Carmean 1956).

2.2.2 Types of Site Index Curves

Site index curves may be anamorphic or polymorphic (Huang and Titus 1993). Anamorphic or “harmonized” (Robichaud 1990) curves result from the fitting of one average or “guide” curve to a series of height-age observations. Subsequent curves are proportional alterations (Plonski 1956, Smith 1984) of the guide curve, resulting in a group of parallel lines with constant slope but different intercepts (Clutter et al. 1992).

Use of anamorphic curves was thought to be the best way to achieve consistency between curves using a small amount of data. However, this method allows only the site index of stands exactly the same age as the reference age to be accurately determined from tree height. It is also biologically unrealistic to assume that growth patterns remain constant for all height classes (Bull 1931) and soil condition (Spurr 1955, Carmean 1956). Use of this method persists due to ease of data collection and curve construction.

Most site index curves developed today are polymorphic (Goelz and Burk 1992). Curve shape ranges from nearly linear on sites with scant water and/or nutrients to sigmoid (S-shaped) or concave where more favorable soil characteristics exist. Polymorphic curves reflect trends in height growth across a variety of site qualities (Avery and Burkhart 2002) and are more consistent with a tree's known growth habits (Brickell 1968). Bull (1931) created early polymorphic site index curves for red pine using data from a variety of soil and site conditions. Suggesting a lack of realism because an anamorphic curve for a poor site had the same shape as a curve for a better site, he illustrated the superiority of polymorphic curves graphically and mathematically. Carmean's work with Douglas-fir (1956) and upland oaks (1972) also showed that site conditions drive polymorphism.

2.2.3 Sources of Measurement Data

Construction of any type of site index curve requires measuring a range of tree heights, ages, and site qualities. Data collection can occur over time from a series of height-age measurements on growing trees or from one-time measurements collected during forest inventory (Brickell 1968). Temporary sample plots (TSPs) are simply locations where tree heights and ages are measured and used to construct anamorphic curves. TSPs are inexpensive but can result in positive or negative correlations between site index and age that can occur if certain site classes are overlooked in the sample. Better sites feature faster-growing trees (and shorter rotation ages) than poorer sites, leading to overrepresentation of poor sites in older age classes.

Permanent sample plot (PSP) data provide reliable, long-term information on growth rates, regeneration, and the extent of tolerance of the stresses of stand establishment and change (Graves 1910). However, the cost is high, and a large number of years must pass before appropriate data become available (Clutter et al. 1992).

Stem analysis, a third form of data collection, involves making incremental measurements of a felled tree's height and age from stump to tip (Bruce and Schumacher 1950) to reveal actual tree growth patterns as they exist in various forests (Brickell 1968, Monserud 1984) on various soil types (Spurr 1955). Stem analysis is labor-intensive (Smith 1984) but allows cone and seed counts, as well as total-stem measurements of branch weight, bark thickness, age, and ring increment, to be made. However, it is often difficult to detect previous damage to the annual leader, such as breakage or terminal bud damage from browse or insect attack (Brickell 1968), which can inhibit height growth (Clutter et al. 1992).

2.2.4 Equation Development and Curve Construction

According to Smith (1984), "good" site index functions are in the form of mathematical equations to facilitate computer modeling. They should be able to consistently estimate site index throughout a range of ages regardless of reference age, and precisely estimate stand height throughout all stages of stand development, Additionally, functions should include as few terms as possible for ease of manipulation (Goelz and Burk 1992).

Curve shape is generally sigmoid. The lower portion shows the slow and monotonic acceleration of early growth (Parresol 1992) to a point of inflection, where the curve begins to progress upward at a steeper angle. The middle portion shows continued growth to a high point, or asymptote; the curve then gently flattens as senescence approaches (Spurr 1955).

The Chapman-Richards function is considered one of the "classical" sigmoidal growth equations (Yin et al. 2003), and has proven sufficiently flexible in forestry to analyze the relationship between age and basal area, diameter, and volume, as well as height-diameter and height-basal area relationships.. It also allows incorporation of variables such as stand density and site quality into height prediction equations if they appear influential (Huang and Titus 1994).

2.3 BLACK SPRUCE SITE INDEX

2.3.1 The Lake States and Canada

Most site index work done for black spruce has occurred in areas where it has commercial value. Gevorkiantz (1957) used Fox and Kruse's (1939) yield tables to calculate site index curves for Minnesota black spruce. Plonski (1956, 1960, 1974) created curves for Ontario black spruce. Payandeh (1991) later developed a four-parameter growth model to express Plonski's yield tables as functions of stand age and site index. Heger (1969) discovered a wide geographic range of applicability for black spruce site index curves using data from Labrador, Manitoba, Newfoundland, and Saskatchewan, an area south of 60° latitude spanning 60° of longitude and 10° of latitude. However, inconsistent data collection weakened the effort. Evert (1970) prepared site index curves for Ontario black spruce using one-time remeasurements of 96 plots established in 1952. Curves corresponded to differences in soil moisture and permeability, lending credence to soils-based site classification.

Heger and Lowry (Heger and Lowry 1971a) calculated height-and-age-based site index curves using stem analysis data from more than 1,000 black spruce trees at 25 locations (124 plots) in Ontario and Newfoundland. They looked for site index curve variation based on breast-height age, crown class, geologic region, soil moisture, and vegetation type, and found differences small enough to permit pooling of data. Table 2.1 presents their results.

Table 2.1. Site index curve differences based on subdivisions of sampled data.

Subdivision Description	Size of Subsample	Curve Difference	Subdivision Description	Size of Subsample	Curve Difference
Age at breast height		< 1.0 ft	Soil moisture		< 2.0 ft
50 to 74	352		Dry	93	
75 to 99	235		Fresh	581	
100+	78		Moist	250	
Crown class			Very wet	208	
Dominant	305	2.1 to 3.0 ft	Vegetation type		< 2.0 to 3.3 ft
Codominant	374		*Calliergon*	290	
Intermediate	297		*Calliergon-Sphagnum*	197	
Suppressed	193		*Calliergon-Cornus*	141	
Climatic-geologic region*			*Sphagnum-Ledum*	68	
Zone A	309	< 1.0 to 2.3 ft	*Calliergon-Petasites*	72	
Zone B	485		*Hypnum-Hylocomium*	36	
Zone C	343		*Kalmia-Vaccinium*	45	
*(Vallee and Lowry 1969)			*Kalmia-Ledum*	72	

Page and van Nostrand (1971) found “a real and meaningful” difference between previously published curves for Newfoundland black spruce and Heger and Lowry’s (1971a) “mainland” curves. Five of the 25 locations sampled by Heger and Lowry had a maritime climate, and only two were actually in Newfoundland. Height differences between central Newfoundland and “mainland” trees ranged from 4 feet at 20 years to more than 6 feet at 80 years. Greater height differences appeared between eastern Newfoundland trees and those growing on the mainland. The authors therefore rejected the assertion that Plonski’s yield tables and site index curves were applicable from Saskatchewan to Newfoundland.

Mead (1978) did a limited study of black spruce in northwestern Ontario; he sampled “at least nine trees” from each of two sites. Admitting that the study was small, he nevertheless maintained that the results could not be extrapolated to other species or site conditions. Payandeh (1978) compared polymorphic site index curves created for 60 black spruce growing on Ontario peatlands to Plonski’s (1956) curves. Even within Ontario, a marked difference existed between height growth of peatland black spruce and those grown on mineral soils. This study demonstrated the potential inadequacy of one equation for describing black spruce height growth across Canada. Table 2.2 shows differences in height increment between curves. Plonski’s curves slightly underestimated height growth of young trees on poor sites, but “grossly underestimated” later height growth. Peatland black spruce reached greater heights than those shown by Plonski’s site index curves and yield tables. Rotation age in such stands might thus be greater. On high sites, Plonski’s curves exaggerated early height growth but underestimated later height growth.

Table 2.2. Height growth increments for peatland (P) and all (A) black spruce.

Age, years	Site index, feet					
	13		26		39	
	P (Payandeh)	A (Plonski)	P (Payandeh)	A (Plonski)	P (Payandeh)	A (Plonski)
25	0.328	0.302	0.584	0.643	0.709	0.879
50	0.423	0.397	0.518	0.558	0.541	0.643
100	0.344	0.230	0.315	0.249	0.285	0.256
200	0.118	0.033	0.092	0.033	0.079	0.033

Others explored subtler characteristics of black spruce growth. Smith (1984) compared asymptotic properties of curves constructed using TSP and stem analysis data with those derived from PSP remeasurement data. Asymptotic properties exhibited in the former two analyses were attributed to sampling techniques where site index was correlated with age. Height estimates from the PSPs showed no strong asymptotic height properties in stands up to 180 years of age.

Smith and Watts (1987) used data from 56 Ontario PSPs to derive curves based on a relationship where height is a function of site index and stand age, and site index is a function of height and stand age. Seven equations were tested under the assumptions that error was present in both the independent variable *S* (site index) and the dependent variable *H* (height), and that height growth was not asymptotic. A linear model (Equation 2.1) fit best ($R^2 = 0.9997$):

Equation 2.1 $H = -1.645S^{0.5} + 0.0012S^3 - (7.7*10^{-7}A^3) - (166.53/A) + 0.023SA - 6.6*10^{-4}S^2A$

Quenet and Manning (1990) studied black spruce in eight different ecological regions in the Yukon Territory by collecting stem analysis data from more than 1,700 trees. They performed a stepwise linear regression of site index on decadal height and published the first polymorphic site index curves for black spruce in the Yukon and north of 60° latitude. Ker and Bowling (1991) used stem analysis data to model height growth for New Brunswick black spruce, but did not plot curves. Payandeh and Wang's (1995) site index curves for Ontario black spruce showed that plantation spruce grow taller than those growing in unmanaged stands on sites of similar productivity and therefore should not be used to estimate productivity in stands of natural origin.

Some recent research involving site index has become more esoteric. Meng et al. (1997) used stem analysis data from naturally regenerated stands of mature to overmature black spruce to create site index curves for New Brunswick black spruce. They used the "pipe model" theory as a basis for their model, stating that each unit of foliage requires a "pipe" of a certain diameter for its physiological processes. The model included calculated cross-sectional sapwood area and leaf area values as variables. More recently, Nigh et al. (2002) prepared climate-specific site index curves for British Columbia black spruce. Their results differed from earlier work by Payandeh (1978) in that they showed relatively constant height growth patterns for black spruce. The authors therefore asserted that their curves would be applicable across Canada.

2.3.2 Alaska Site Index

The assumption that curves prepared for Canada and the Lake States can accurately describe and predict height growth of the species in Alaska may not be valid. Previous work done by Page and van Nostrand (1971), Mead (1978), and Payandeh (1978) helps confirm the need for region-specific site index curves for Alaska. Published, Alaska-specific site index curves exist for white spruce, quaking aspen, paper birch, and balsam poplar-black cottonwood; only balsam poplar-black cottonwood equations are polymorphic. The only study of the height-age relationship in Alaska black spruce was performed by DeVolder (1999), who briefly analyzed fire-killed lowland black spruce heights and ages as part of a fire history and dendrochronology project on the Kenai Peninsula. DeVolder used linear equations to compare height-age patterns of two sites and did not create site index curves.

Table 2.3 summarizes existing published site index information for black spruce.

Table 2.3. Summary of tree data from previous preparations of site index curves.

Year	Author(s)	Region	n	Total Height, feet		Age at BH, years		SI, feet	Ref Age
				Mean	Range	Mean	Range	Range	
1957	Gevorkiantz	Minnesota	n/a	40*	10–70	100	20–120	20–60	50
1968	Heger	Labrador	102	15	5–33	n/a	5–45	8–36	50
1970	Evert	Ontario	n/a	10–56	7–65	75	21–121	40–60	100
1971	Heger & Lowry	Eastern Canada	1169	n/a	n/a	n/a	50–240	10–50	50
1971	Page & van Nostrand	Newfoundland	n/a	n/a	n/a	n/a	10–100	30–50	50
1974	Plonski	Ontario	n/a	n/a	32–89	85	20–150	16–46	50
1978	Mead	Ontario	20	n/a	n/a	n/a	n/a	40	50
1978	Payandeh	Ontario	60	45	22–71	132	43–287	2–39	50
1987	Smith & Watts	Ontario	122	59	14–81	103	56–138	32–67	100
1990	Quenet & Manning	Yukon	1732	n/a	n/a	n/a	10–150	7–49	50
1991	Ker & Bowling	New Brunswick	354	52	23–83	80	50–203	12–57	50
1995	Payandeh & Wang	Ontario	n/a	n/a	n/a	n/a	n/a	7–20	15
1997	Meng et al.	New Brunswick	700	n/a	n/a	n/a	n/a	23–62	50
1999	DeVolder	Kenai Peninsula	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2002	Nigh et al.	British Columbia	182	52	26–82	100	51–174	16–56	50

Although published curves for black spruce from other regions may provide general assessments of productivity in Alaska, they are based on the soil and site conditions of myriad regions and often do not adequately cover the full range of heights that this species can attain. Alaska-specific productivity estimates of black spruce are needed in anticipation of increased demand for non-timber resources of the boreal forest (Nigh et al. 2002). Now that total biomass utilization and global carbon dynamics have become major issues, interest in smaller trees is greater than ever before (Yuancai and Parresol 2001).

2.4 FIELD METHODS

2.4.1 Stem Analysis

In 2001 and 2002, 33 stands of the black spruce cover type as defined by Eyre (1980) were sampled in the Tanana Valley between Fairbanks and Northway. Using Eyre's parameters, predominance of black spruce (at least 50% of the stocking) was the major criterion for stand selection; many stands were “pure” (at least 80% of the stocking). These data augment a smaller set of stem analysis data collected between 1984 and 1993 by UAF forest technicians who followed a procedure identical to that used here and sampled 25 sites in southcentral Alaska, the Tanana Valley, and the southern slopes of the Brooks Range. The 292 trees sampled specifically for site index were also included in the larger sample that formed the basis for a new individual-tree volume equation. The objective was a dataset encompassing the widest possible variety of slopes, aspects, elevations, heights, and ages.

We selected four to six dominant or codominant trees that were at least 50 years old at breast height based on general estimates of age obtained with an increment borer, avoiding those with broken tops or excessive crook, lean, and scarring. Black spruce was positively identified using a hand lens to find the reddish- to cinnamon-colored pubescence on the current year’s growth (Sargent 1933, Viereck and Little 1972). Forked tops were common on even the “best” trees and were occasionally not discovered until after felling because cones and foliage obscured them. Forks less than 3 feet in length were allowed in the absence of any other defect, but trees with longer forks were discarded.

Standardized measurements included height (total length of stem), stump height (0.5 feet from ground), diameter (outside bark to nearest 0.1 inch), DBH (diameter at 4.5 feet), and live crown length (to nearest foot, starting at height of lowest large vigorous branch). Trees were marked at stump height and breast height before falling. Once felled, trees were marked every 4.0 feet from breast height to the tip; top sections were occasionally less than 4.0 feet. If a top was forked, the largest fork represented the main stem. Crown class, total height, and live crown length for each tree were recorded on a field data sheet (Appendix J). At each 4.0-foot mark we cut a cross-section of the stem and marked each with tree letter and disk number. Outside-bark diameters of each disk were recorded; the topmost disks were often less than 1 inch in diameter and were hand-clipped. Plastic bags containing complete sets of disks for each tree were marked with the site number, location, and number of trees cut.

Figure 2.1 shows all of the sites where trees were sampled for stem analysis (map created by the author).

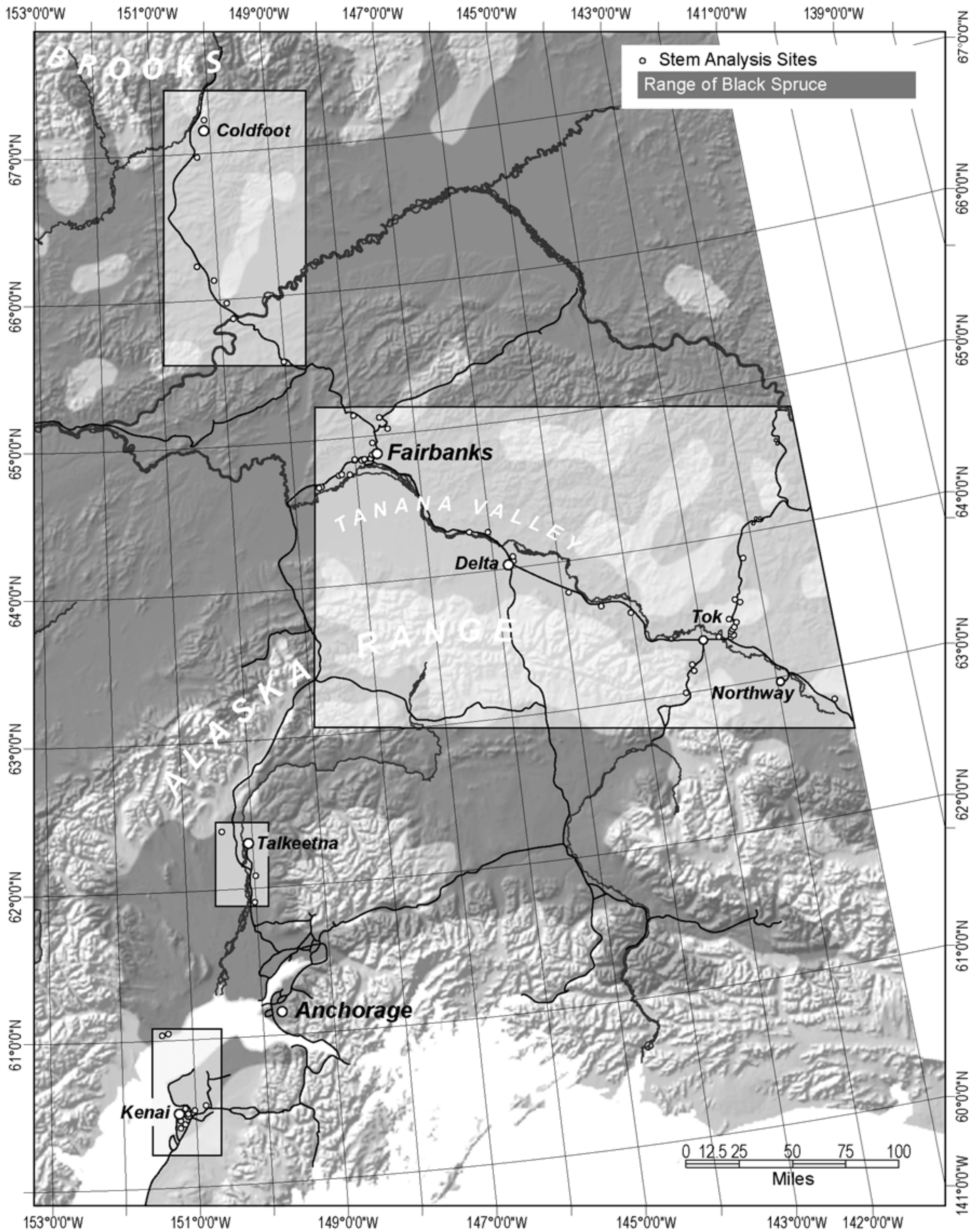

Figure 2.1. **Stem analysis sites, 1984–2001.**

2.4.2 Additional Site Data

We recorded each plot's aspect, slope, slope position, contour, and GPS coordinates, and estimated the likelihood of permafrost and type of soil parent material based on knowledge of local geomorphology. We dug a soil pit to a maximum depth of 3.3 feet (1 meter); however, most pits were commonly 8 to 20 inches deep. Bedrock was seldom reached due to seasonally or permanently frozen soil. The color, moisture, texture, and thickness of visible soil horizon were noted as well as excessive moisture, seasonally frozen soil, charcoal, or volcanic ash. Volcanic ash layers in the upper soil horizons were common at sites east of Delta Junction. Appendix F summarizes the physiographic features of each site.

Over- and understory trees, shrubs, herbs, grasses, and bryophytes in the immediate vicinity were identified and listed; particular attention was paid to bryophytes because they are such an outstanding feature of black spruce stands. Positive identification of some bryophytes is possible only with chemical analysis. Since the objective was a general assessment of vegetation communities, field identification sometimes stopped at the genus level, especially with *Cladina* and *Cladonia*, lichen genera that include numerous subtly different species.

A cover class was assigned to each plant species, based on a scale provided by Daubenmire (1968) to make general estimations of species cover regardless of species overlap. Cover classes are by percent, i.e., Trace=T (<1.0%); 1=1–5%; 2=5–25%; 3=25–50%; 4=50–75%; 5=75–95%; 6=95–100%. The "Trace" category was added so that slightly represented species would not be over-represented. Cover estimates were made of dead wood, forest litter, and mineral soil. Appendix G lists plants found at each site by species and cover class.

2.5 LABORATORY METHODS

2.5.1 Tree Age

Disks were segregated by site and air-dried for at least three weeks. A power belt sander with 80-grit sandpaper was used to sand one side of each disk to better reveal the very closely spaced growth rings. Even the "best" black spruce seldom grew straight throughout their entire lifetimes and almost all disks showed evidence (e.g., uneven ring increment across the cut surface) of the tree's efforts to remain upright on soils often shallow over permafrost. We judged a single “average” radius to reflect true radius. Some lower stem sections were severely decayed, making ring counts impossible.

Ring increments were measured to the nearest 0.001 millimeter on a sliding-stage micrometer (Velmex Inc. 1992) and summarized with Measure J2X tree ring measuring software (VoorTech Consulting 1999, VoorTech Consulting 1999). For each disk, Measure J2X produced a set of ring widths in decadal format exportable to a spreadsheet. Table 2.4 is a sample of output. Disk age is the last year measured minus the first year measured (2000-1880 = 120 years). For disk 08AA_5, a ring 0.710 mm wide was added in 1880; in 1881 the tree put on 1.675 mm of growth, etc.; –9999 denotes the end of the file. Although site index equations do not require ring increment measurements, these data are essential for studies of suppression, release, disturbance, disease, and annual volume accumulation (Shaw 1994). They also provide a check to minimize counting errors and identify anomalous growth changes not necessarily related to productivity.

Table 2.4. Increment measurements for Site 8, Tree AA, Disk 5.

Disk	Decade/Yr	00	01	02	03	04	05	06	07	08	09
08AA_5	1880	710	1675	1918	648	2009	1993	1228	1637	858	1054
08AA_5	1890	1131	1360	1258	933	892	792	539	505	416	532
08AA_5	1900	471	640	714	539	433	709	1125	929	912	662
08AA_5	1910	544	981	663	649	795	885	802	1073	945	779
08AA_5	1920	1005	952	549	1138	580	729	627	952	840	1023
08AA_5	1930	979	1067	1129	1133	846	877	1037	720	870	1122
08AA_5	1940	543	503	850	1253	938	806	670	915	737	695
08AA_5	1950	957	574	904	694	787	1006	907	660	471	585
08AA_5	1960	879	898	1108	796	939	1068	1096	921	874	679
08AA_5	1970	756	951	731	768	946	645	853	555	416	778
08AA_5	1980	721	884	1060	876	836	1003	490	446	604	463
08AA_5	1990	618	348	367	404	417	440	658	750	528	536
08AA_5	2000	526	–9999								

2.5.2 Preliminary Height-Age Trends

Preliminary height-age trends for each site were next plotted and inspected. Plots showed evidence of single- and double-cohort stands as well as considerable variation in growth rate. Variations in growth such as these may result from suppression, especially in younger trees that often show rates of slower growth. Early suppression can cause marked differences in height that have no connection to differences in site quality (Stage 1963). However, suppression is difficult to judge in black spruce because it is among the most shade tolerant of conifers (Millar 1936). In addition, height-age trends of black spruce are unique in that they can show a systematic variation in height increment over a span of decades. This is probably due to changes in crown class over time. Heger (1968) attributes random, shorter-term variation in height increment to climatic variation. Figure 2.2 shows a two-cohort stand. Figure 2.3 illustrates similar growth rates but variation in age, while Figure 2.4 shows a uniform height-age distribution; both sets of curves support the idea of site index as a useful indicator of forest productivity.

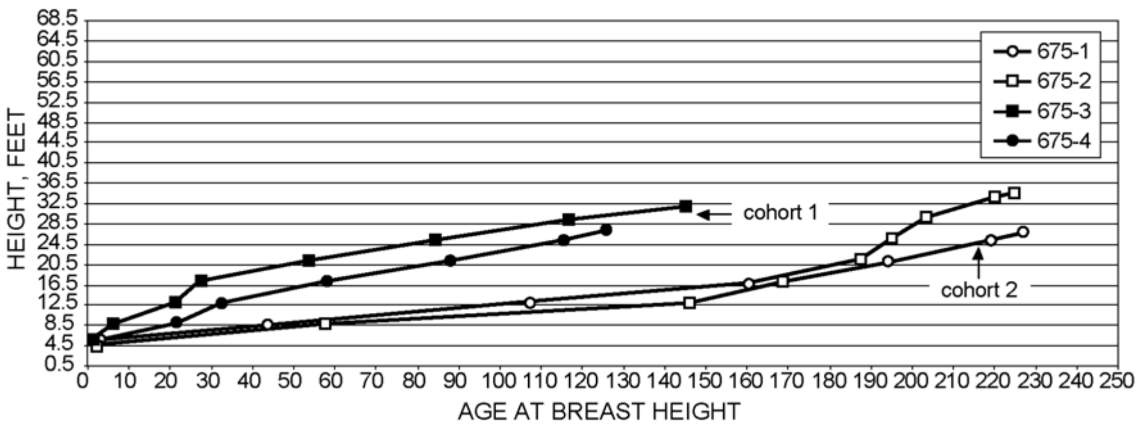

Figure 2.2. **Two-cohort stand at site 675.**

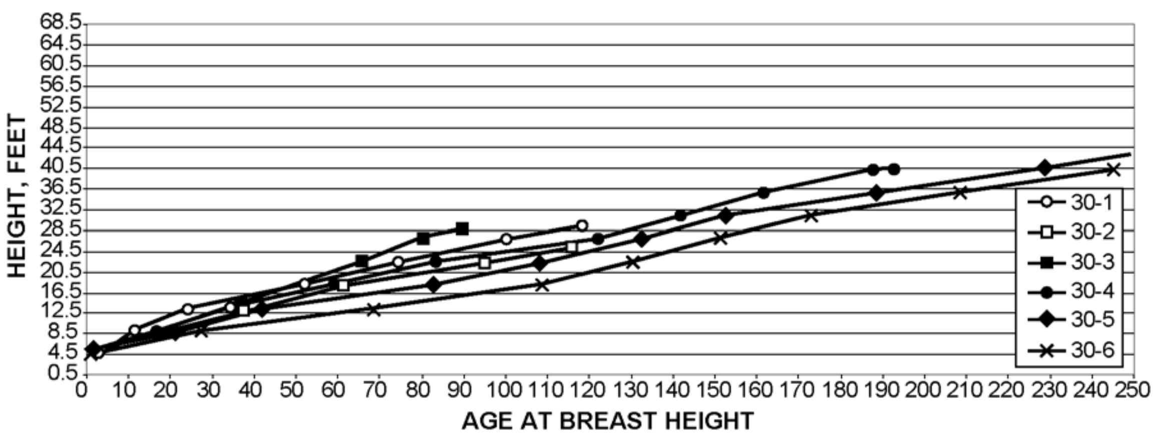

Figure 2.3. **Equal growth rates but age differences at site 30.**

Figure 2.4. Uniform height-age pattern at site 622.

2.6 CALCULATED DATA

2.6.1 Age to Breast Height

Age data were stratified into six elevation classes: 1 (100–500 feet); 2 (501–1,000 feet); 3 (1,001–1,500 feet); 4 (1,501–2,000 feet); 5 (2,001–2,500 feet); and 6 (2,501–3,000 feet). Age data were pooled for all trees felled for site index and volume. Age to breast height was calculated by subtracting breast-height age from stump age. Summary statistics were derived using the MEANS procedure in SAS (SAS Institute 2002).

2.6.2 Disk Height and Age Adjustments

Trees less than 50 years old at breast height were eliminated from the sample since no direct calculation of site index could be made (Ker and Bowling 1991, Nigh et al. 2002). The final sample size was 240 trees, or 2,136 height-age pairs. Height at each section point required adjustment because this point seldom occurs exactly at the terminal bud and can be as much as four feet lower than the "actual" tip of the tree (top sections obviously need no adjustment). Heights at the point of sectioning were recalculated according to Carmean's (1972) method, which is considered the most accurate (Ker and Bowling 1991). Assuming cuts were made at the middle of the annual leader, section heights were adjusted by half of its estimated length:

Equation 2.2 $$H_{section} = (H_{i+1} - H_i)/[2(N_i - N_{i+1})]$$

where $H_{section}$ = tree height at the point of sectioning; H_i, H_{i+1} = heights of disks *i* and *i+1*; and N_i, N_{i+1} = ring counts (ages) of disks *i* and *i+1*.

Each disk age was then recalculated as "breast-height age" to allow comparison of like ages. Age at breast height represents the height at which a species has begun to exhibit its characteristic growth abilities. Its use takes advantage of a stronger statistical relationship that exists between height and breast-height age than between height and total age (Ker and Bowling 1991) without compromising the relationship between height and age (Husch 1956).

Disk ages were adjusted according to the assumption that a tree exactly 4.5 feet tall is zero inches DBH (Czarnowski 1961) and is a year old at breast-height, because year 1 is the first year that a tree is 4.5 feet tall. For example, a ring count of a stem section cut at 4.5 feet reveals an age of 60; the age of a section taken farther up the stem at 16.5 feet equals 49. "Breast-height age" at 16.5 feet is actually (60-49)+1, or 12. All disk ages were adjusted in this manner. By the same reasoning, stump age also equals 1, but "stump age at breast height" is less than zero (actual age at breast height minus actual age at the stump, plus 1 year) because the tree is not yet 4.5 feet tall. Values for "stump age at breast height" were therefore deleted. Adjusted heights and ages were then used to interpolate "site index" for each tree using Equation 2.3:

Equation 2.3 $$SI = H_1 + [H_a * (A - H_2)]$$

where SI = site index; H_1, H_2 = disk heights corresponding to breast-height ages above and below 50 years; H_a = average height increment attained between the breast-height ages corresponding to heights H_1 and H_2, and A = reference age (50 years).

2.7 STATISTICAL ANALYSES

Linear equations were first tested for their ability to describe the height-age relationship of Alaska black spruce; these were fitted to a subsample of the data using the REG procedure in SAS (SAS Institute 2002). Site index for a subsample of 83 trees ranged from 20 to 30 feet. This range was considered an average indication of site quality for Alaska black spruce; a strong linear relationship existing for the subsample would likely hold true for all trees.

Equations 2.4, 2.5, 2.6, and 2.7, from Carmean's (1972) list of models, were tested:

Equation 2.4 $H = \pm a + b(age) - c(age)^2$

Equation 2.5 $H = \pm a + b(age) - c(age)^3$

Equation 2.6 $H = -a + b(age)^{1/2} \pm c(age)$

Equation 2.7 $H = -a + b(age)^{1/3} + c(age)$

where H = predicted total height; age = breast-height age; and a, b, c = parameters to be estimated. Figure 2.5 illustrates the results.

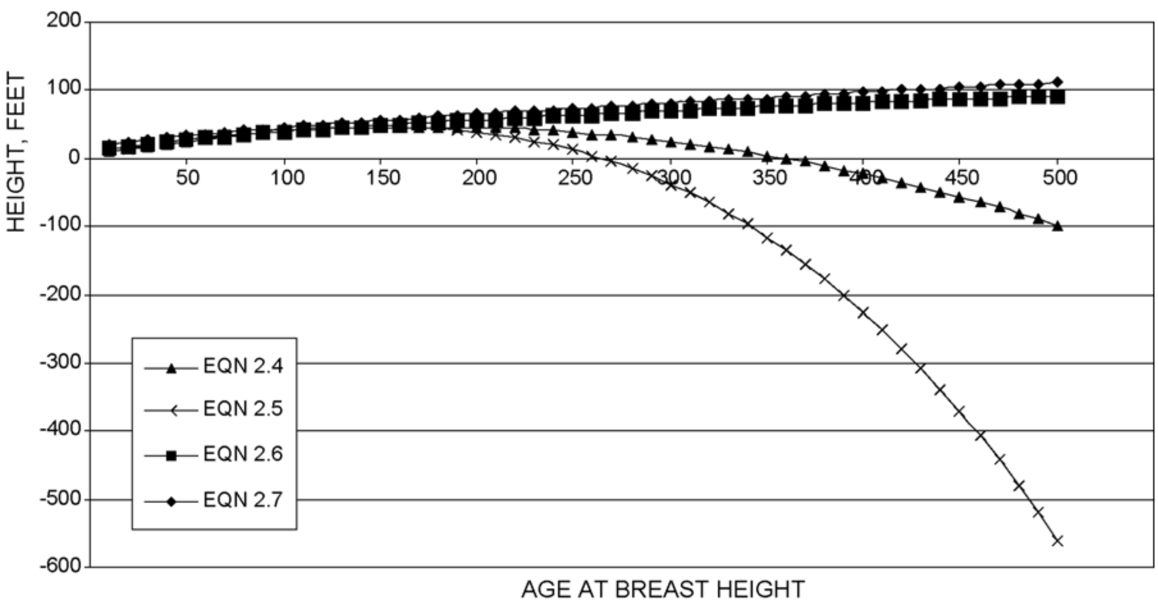

Figure 2.5. Linear regressions of height on age for Alaska black spruce.

It is apparent that none of these equations can describe height growth. Equations 2.4 and 2.5 produce illogical curves that show decreasing height with increasing age. Equations 2.6 and 2.7 lack an inflection point and an asymptote; they continue upward without reaching some maximum height, even beyond age 300. An inflection point and an asymptote are required to accurately describe growth (Goelz and Burk 1992, Robichaud and Methven 1993).

The coefficients of a nonlinear function were determined using the parameter prediction method. Parameter prediction is probably the most common method used to develop site index equations (Clutter et al. 1992). Schnute (1981) asserts that "there is an art to choosing the right parameters for a particular nonlinear model" and offers three guidelines. First, parameters should relate directly to the data; ideally, they should correspond to actual points on the growth curve. Second, parameters should not be highly influenced by changes in the model. These "local" guidelines focus on a model's dependence on its parameters. The third guideline is "global" in scope. As parameters approach the limits of model definition, i.e., infinite values, they should not define a potentially useful curve. Any useful curve should correspond to a finite point.

Data were stratified into 5-foot height classes based on each tree's interpolated site index. Stratification minimizes bias arising from a possible correlation between age and site quality (Carmean 1972). A separate height-age function was fit to each height class; each set of estimated parameters was used to create class-specific height-age curves. The strength of the relationship between parameter estimates and site index could then be investigated, expressed as functions of site index, and substituted back into the original function. The "expanded" model was then re-fitted to the entire dataset to produce polymorphic curves (after Smith and Watts 1987).

The Chapman-Richards model (Richards 1959) was used to estimate parameters because it is a proven and reliable descriptor of growth. Equation 2.8 shows the function, with the parameters defined for forestry by Carmean (1956):

Equation 2.8 $$H = a\,(1 - e^{-b(age)})^{c}$$

where a = asymptotic height; b = rate (slope) of height growth, c = pattern of initial growth (curve shape); and e = base of natural logarithms. The NLIN procedure in SAS (SAS Institute 2002) was used to solve for equation parameters and produce a curve for each height group. Unlike the REG procedure, NLIN depends on user-supplied starting values to iteratively estimate model parameters. These values are re-estimated and improved until the model "converges" on a solution; i.e., the error sum of squares changes less than some threshold amount (Fang and Bailey 1998). Convergence criteria are not always met due to the complexity of the iterative process.

The range of starting values was based on examinations of the data and on values obtained from CurveExpert, a curve-fitting utility developed by Hyams (1995). Preliminary curves for each group were plotted in Excel (Microsoft Corp. 2001) using parameter estimates and a breast-height age of 50. Table 2.5 shows initial parameters and site index values.

Table 2.5. Initial parameter estimates from stratified site index data.

Site Index Class	Number of Trees	Max Top Height	Parameter			Model Converge?	Calculated Site Index
			a	*B*	*c*		
5.0**–9.9	8	48	29.3923	0.020500	2.5051	Y	9.6
10.0–14.9	35	40	543.4000*	0.000059*	0.6223*	N	14.5
15.0–19.9	56	47	656.5000*	0.000078*	0.6400*	N	18.8
20.0–24.9	39	67	382.5000*	0.000227*	0.6240*	Y	23.3
25.0–29.9	46	56	61.0336	0.007440	0.6926	Y	27.2
30.0–34.9	30	57	65.9998	0.008640	0.6911	Y	31.9
35.0–39.9**	24	58	69.7799	0.009760	0.6947	Y	36.0

**Values not used to estimate the relationship between parameters and site index.*

***Calculated site index values ranged from 7.2 to 38.6.*

2.7.1 Model Expansion

Because they differed for each height class, parameters *a*, *b*, and *c* were hypothesized to be functions of site index; that is, the asymptote, growth rate, and curve shape would vary with site index (site quality) (Clutter et al. 1992). The strength of each parameter's relationship with site index was determined using simple linear regression and plotted in Excel (Microsoft Corp. 2001); Figure 2.6 uses the strong relationship between parameter *a* and site index as an example. Extremely high estimates of parameter *a* (marked with an asterisk in Table 2.5) were not used to establish a relationship between each parameter and site index because they negated this relationship.

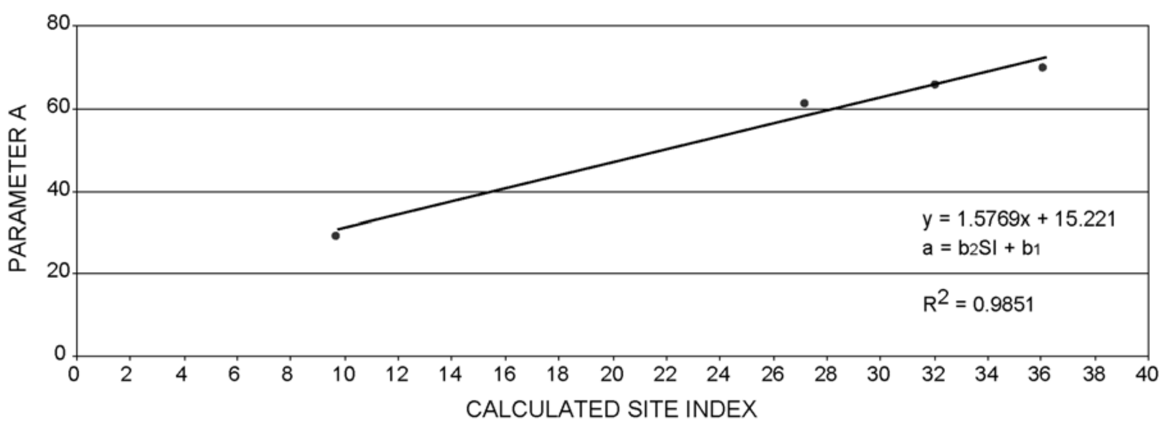

Figure 2.6. Regression of height group parameter *a* on site index.

All parameters were expressed as functions of site index ("expanded") in order to create a system of polymorphic curves. Goelz and Burk (1992) list 17 methods of varying complexity used for parameter expansion. Here, parameters were expanded with linear models:

Equation 2.9 $a = b_1 + b_{2,}SI$

Equation 2.10 $b = b_3 + b_{4,}SI$

Equation 2.11 $c = b_5 + b_6 SI$

where *a, b, c* = existing equation parameters; *SI* = site index; and b_1, b_2, b_3, b_4, b_5, b_6 = parameters to be estimated. Coefficients from the three linear equations describing the relationship of site index to parameters *a*, *b,* and *c* served as starting values for predicting final parameters for the entire data set. Using the parameter *a*-expansion example shown in Figure 2.6, parameter b_2 would have a starting value of 1.5769; parameter b_1, 15.221. Starting values for parameters b_3, b_4, b_5, and b_6 were derived in a similar manner. Height at breast-height age was set equal to 4.5 feet, because breast-height age (not total age) was used as a variable. Equation 2.12 shows the polymorphic, height-adjusted form of the Chapman-Richards function:

Equation 2.12 $H = 4.5 + (b_1 + b_2 SI) * [1 - e\ (age * (-b_3 - b_4 SI))]^{(b_5 + b_6 SI)}$

where *H* = adjusted height; *age* = breast-height age; *SI* = calculated height at breast-height age 50; and b_1, b_2, b_3, b_4, b_5, b_6 = parameters to be estimated. The expanded model met convergence criteria when re-fitted to the data; multiple runs were made, using different sets of starting values, to ensure that the sum of squares obtained was a global minimum and not a local minimum (Neter et al. 1996). The full system of polymorphic curves was plotted in Microsoft Excel (Microsoft Corp. 2001) using final parameter estimates. Table 2.6 shows final regression results. No confidence interval included zero, indicating significance (p=0.05) of all parameters.

Table 2.6. Results of nonlinear regression on site index data.

The NLIN Procedure: Expanded Chapman-Richards Equation for Site Index						
Parameter	Estimate	Approximate Standard Error	Approximate 95% Confidence Limits			
			Lower		Upper	
b_1	40.8932	1.9034	37.1603		44.6260	
b_2	0.4015	0.0561	0.2914		0.5116	
b_3	0.00175	0.000336	0.00109		0.00241	
b_4	0.000418	0.000026	0.000368		0.000468	
b_5	1.4424	0.0501	1.3442		1.5406	
b_6	-0.0118	0.00139	-0.0146		-0.00910	
Summary Statistics						
Source		Degrees of Freedom	Sum of Squares	Mean Square	F Value	Pr > F
Regression		6	1263251	210542	23737.4	<.0001
Residual		2130	18892.3	8.8696		
Uncorrected Total		2136	1282143			
(Corrected Total)		2135	294837			
R^2 = 1-(Residual SS / Corrected SS)		0.9359				

2.7.2 Site Index Model Behavior

Prediction bias, defined as the range of over- or under-prediction of site index, was calculated for the entire sample by subtracting predicted height from actual (adjusted) height. Mean prediction bias for the sample was 0.04 feet; standard deviation was 2.97 feet. Table 2.7 shows prediction bias by height class.

Table 2.7 Model height prediction bias by height class.

Height Class	5	15	25	35	45	55	65
Height Range, feet	0.0-9.9	10.0-19.9	20.0-29.9	30.0-39.9	40.0-49.9	50.0-59.9	60.0-69.9
Number of Trees	473	484	683	344	127	21	4
Mean Bias, feet	-0.18	-0.37	-0.37	0.21	2.28	7.35	19.07
Standard Deviation	1.26	2.08	2.44	3.48	5.36	6.06	2.68

Bias was also calculated by site index (Table 2.8) and breast-height age (Table 2.9) to assess if site index prediction was more prone to error for certain tree sizes or ages.

Table 2.8 Model height prediction bias by site index.

SI Class	10	20	30	40
SI Range, feet	5.0-14.9	15.0-24.9	25.0-34.9	35.0-44.9
Number of Trees	323	833	718	262
Mean Bias, feet	-0.29	0.32	-0.09	-0.14
Standard Deviation	3.99	3.28	2.33	1.76

Table 2.9 Model height prediction bias by breast-height age.

Age Class	25	75	125	175	225
Age Range	1-50	51-100	101-150	151-200	201-260
Number of Trees	1225	594	242	66	9
Mean Bias, feet	0.09	-0.32	0.86	-0.66	-1.27
Standard Deviation	1.57	2.76	5.91	6.28	3.55

Residuals were plotted in Excel (Microsoft Corp. 2001) against site index (Figure 2.7) and breast-height age (Figure 2.8).

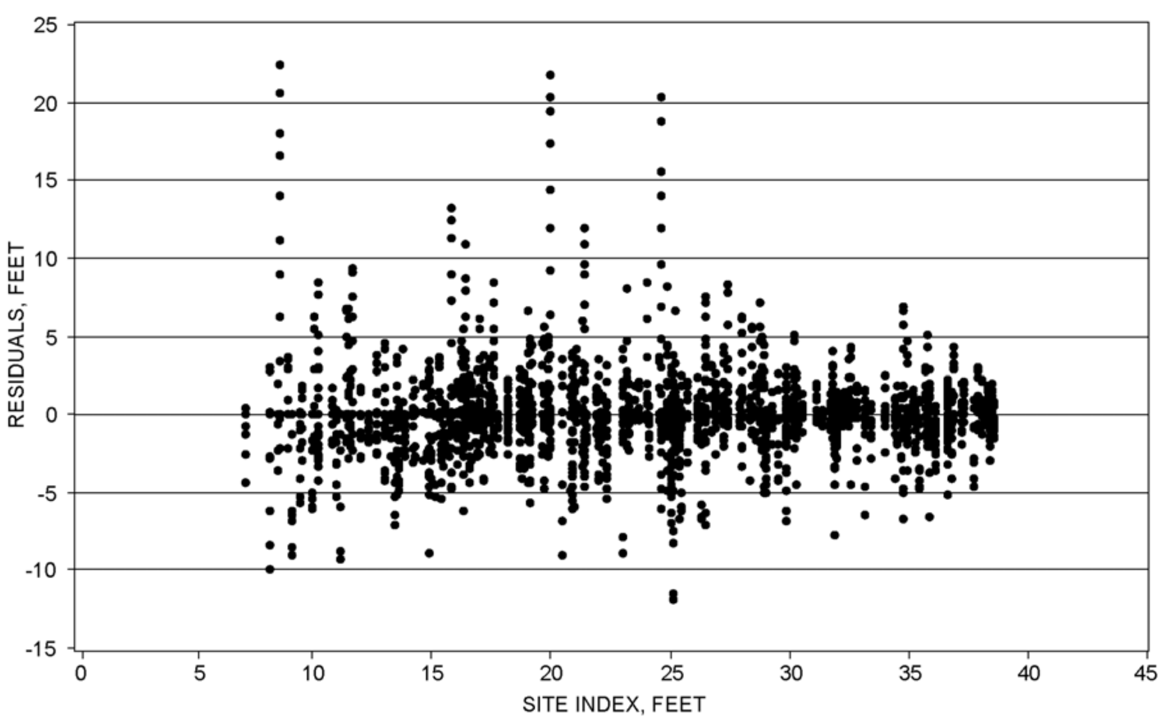

Figure 2.7. Residuals (actual height–predicted height) versus site index.

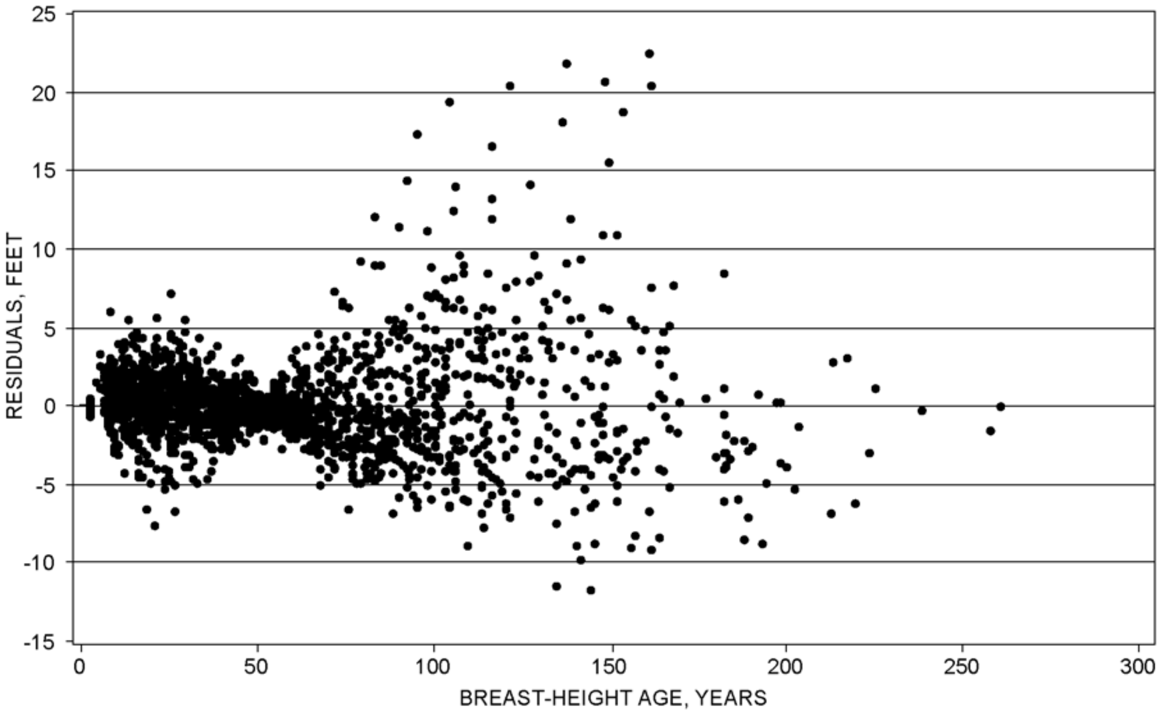

Figure 2.8. Residuals (actual height-predicted height) versus breast-height age.

2.8 RESULTS AND DISCUSSION

Equation 2.13 shows the first individual-tree height predictions for Alaska black spruce. Curves represent a height range of 8.6 to 37.9 feet at 50 years breast-height-age:

Equation 2.13

$$H = 45.3932 + .4015SI * \{[1 - e^{AGE*(-.00175\ -\ .000418\ SI)}]^{(1.4424\ -.0118\ SI)}\}$$

The model fits the data well, as indicated by a mean squared error (MSE) of 8.8696 and the fact that the model was able to predict almost 94% of height variation. The mathematical properties of the sigmoidal function used as a basis for this equation and the use of the parameter prediction method reflect biologically reasonable curve shapes (Huang and Titus 1994). The realistic predictions of height made by the curves within the observed range of data seem to remain reasonable upon model extrapolation that begins to occur at approximately 160 years of age. Figure 2.9 shows the curves and the height-age points that formed the basis for the model.

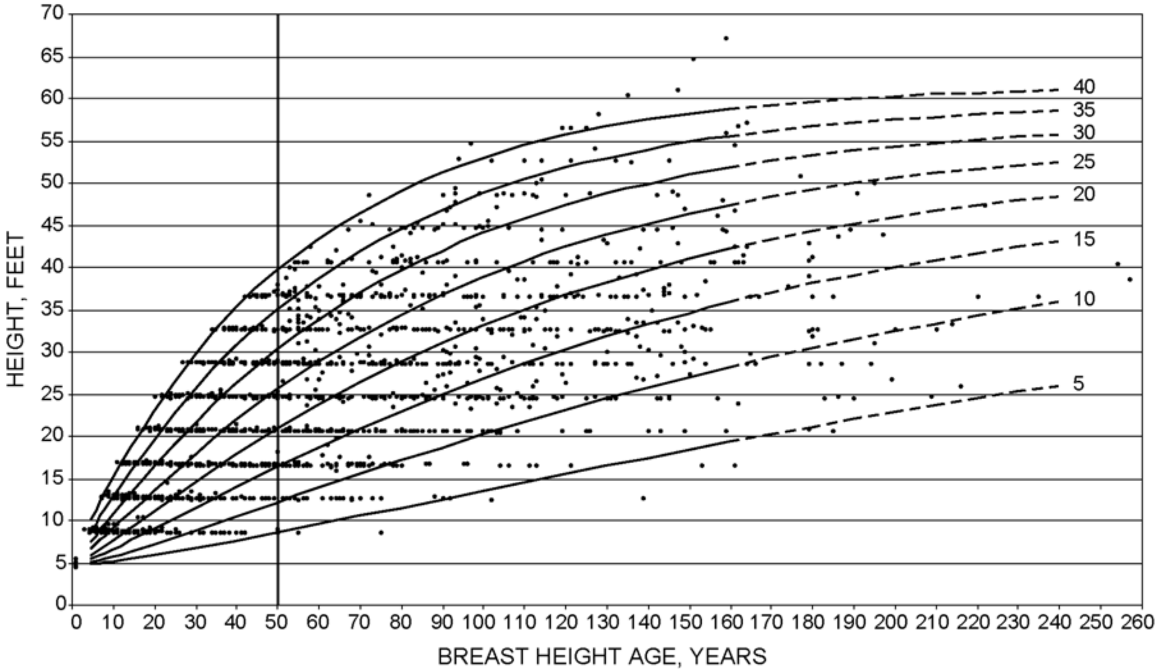

Figure 2.9. Site index curves for Alaska black spruce.

2.8.1 Prediction Bias, Curve Adjustment, and Residuals

Curves passed exactly through, or very close to, the reference age of 50 years for height classes represented by SI 20 and greater. Most of the error centered on predicting height for height classes 5, 10, and 15. Mean prediction bias was low (0.04 feet) for the entire sample. Bias by height class (Table 2.7) remained low (-0.37 to 0.21 feet) up to height class 55, which had only 21 trees that were 50 feet and taller. The relatively small amount of larger trees likely explains the drop in model accuracy that occurred in the taller height classes; overestimations of height ranged from 4 to 20 feet. Prediction bias remained low across site index classes (Table 2.8) and breast-height age classes (Table 2.9). Height and age groups were as represented as well as possible for road-accessible sites; however, it was difficult to find many trees taller than 60 feet. This model can therefore be considered accurate for predicting heights of black spruce up to 50 feet tall, but should be used with caution when working with larger trees.

One shortcoming of parameter prediction to model site index is the lack of a guarantee that tree height equals site index when breast-height age equals base (reference) age (Shaw and Packee 1998). Equations may be mathematically “conditioned” to force curves to pass through their respective index heights at the reference age (Ker and Bowling 1991). Shaw and Packee (1998) discuss a “strictly aesthetic” solution that involves iteratively solving for site index and inserting the result into the equation to solve for height at age 50. The result is likely to differ from the iteratively solved value, so the original site index estimate is multiplied by a correction factor (derived by dividing expected site index by height at age 50). This adjusts the estimate and forces the curve to pass through the reference age. These curves might therefore be considered “preliminary” or “unconditioned.”

Residual plots (Figure 2.7 and Figure 2.8) indicated a good fit. Residuals plotted against site index generally showed a homogeneous band of points about the mean. Height overestimation appeared at 10, 20, and 25 feet; this is consistent with the higher (greater than 3) standard deviations shown in Table 2.8 for SI 10 and 20. This may be due to unusually good growing conditions, e.g., better soils, more precipitation, or warmer air temperatures. Residuals plotted against breast-height age yielded a plot that looks like an hourglass laid on its side; this is to be expected because the model used was reference-age dependent (Shaw and Packee 1998).

2.8.2 Comparison with Other Curves

Curves developed by Gevorkiantz (1957) and Heger and Lowry (1971a) were chosen for comparison with the Alaska curves because both were calculated as height in feet at reference age 50 for a similar range of tree sizes. Low-productivity sites represented by SI 20 and 30 appeared to produce trees that were almost equal in height at 80 and 100 years, suggesting that poor sites are not region-specific. However, significant height differences appeared at moderately productive (SI 40) sites; heights of Alaska trees began to lag behind Lakes States and eastern Canada trees that were equal in height. Extrapolation was necessary to estimate heights of Alaska trees at SI 45; estimates, however, showed that this “lagging” pattern continued; height differences increased to 7 to 10 feet. Table 2.10 summarizes the comparison results.

Table 2.10. Selected site index curves compared across regions.

SITE INDEX	ALASKA (2004)		LAKE STATES*		EASTERN CANADA**	
	Height at 80 Years	Height at 100 Years	Height at 80 Years	Height at 100 Years	Height at 80 Years	Height at 100 Years
20	28	32	26	29	28	32
30	40	44	40	44	42	48
40	48	52	54	59	54	60
45	53*	57***	60	67	59	65

*(Gevorkiantz 1957); **(Heger and Lowry 1971b); *** *Visually extrapolated from height-age data.*

Figure 2.10 compares tree heights at age 80 across the three regions at the site indices listed in Table 2.10. Alaska black spruce heights are similar to those in other regions for the SI 20 and 30. However, on better sites (SI 40 and 45) Alaska tree heights are significantly lower than those in other regions. In conclusion, new curves developed for Alaska black spruce show that better sites in Alaska are not comparable to better sites elsewhere.

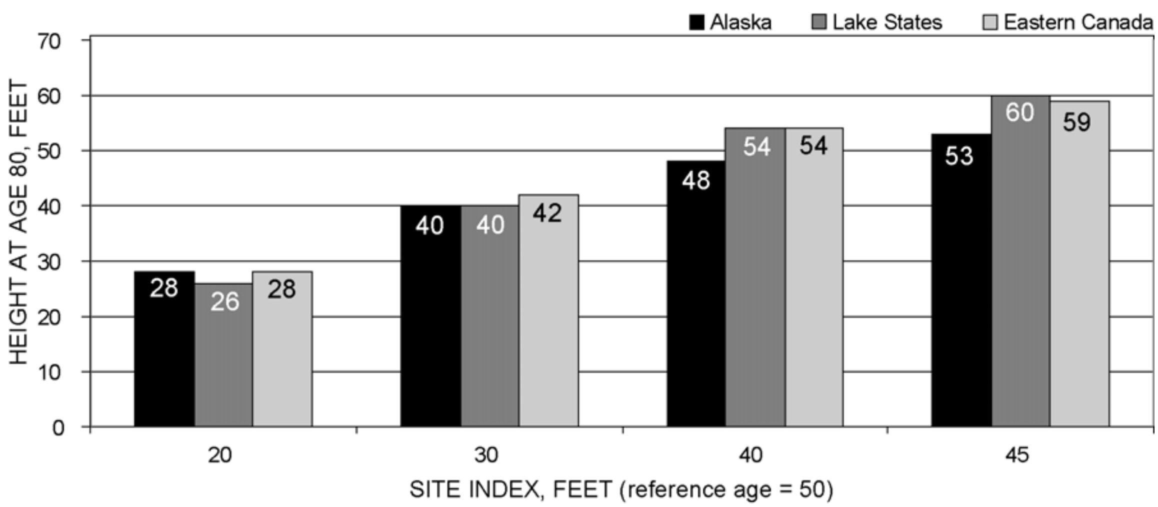

Figure 2.10. Tree height at age 80 compared across regions.

The general effects of cold, wet soils appear to combine to produce slow growth rates in Alaska black spruce. Many of the trees sampled, especially those less than 20 feet tall, had not begun to exhibit declines in height growth, even though they were quite old. This resulted in high estimations of the *a* (asymptotic height) parameter, which were considered unusable for defining any relationship between the parameter estimate and site index. While growth is more typically curvilinear on better sites, it is close to linear on very poor sites and remains so for many years. The idea that poorer sites support the oldest stands because stands on better sites reach merchantable size and are harvested sooner does not hold true for Alaska. The stands sampled across Alaska for site index were almost certainly never harvested; therefore, the site index curves shown here are quite realistic.

2.8.3 Age-to-Breast-Height

663 of the trees sampled for volume and site index had stump- and breast-height disks available for measurement. Total age, however, is not revealed by ring counts, even on stumps, of

black spruce growing in deep moss; “total age” can therefore vary widely depending on the stem measurement location. Because buildup of the forest floor over time causes development of adventitious roots (LeBarron 1945), total age should be measured beneath the soil surface at the earliest set of roots. Desrochers and Gagnon (1997) found that such age measurements made below adventitious roots could add 3 to 19 years to estimates made at ground level. Table 2.11 summarizes sample tree breast-height ages.

Table 2.11. Sample tree ages.

Age Type	Mean	Standard Deviation	25th Quartile	75th Quartile
Stump Age (0.5 feet)	108	48	69	145
Breast Height Age (4.5 feet)	83	46	50	113
Age to Breast Height	26	15	14	33

Figure 2.11 depicts ages by elevation class. Mean age-to-breast-height remained constant across elevations. Trees growing at 500 to 1,000 feet are approximately 30 to 60 years younger than those at higher and lower elevations.

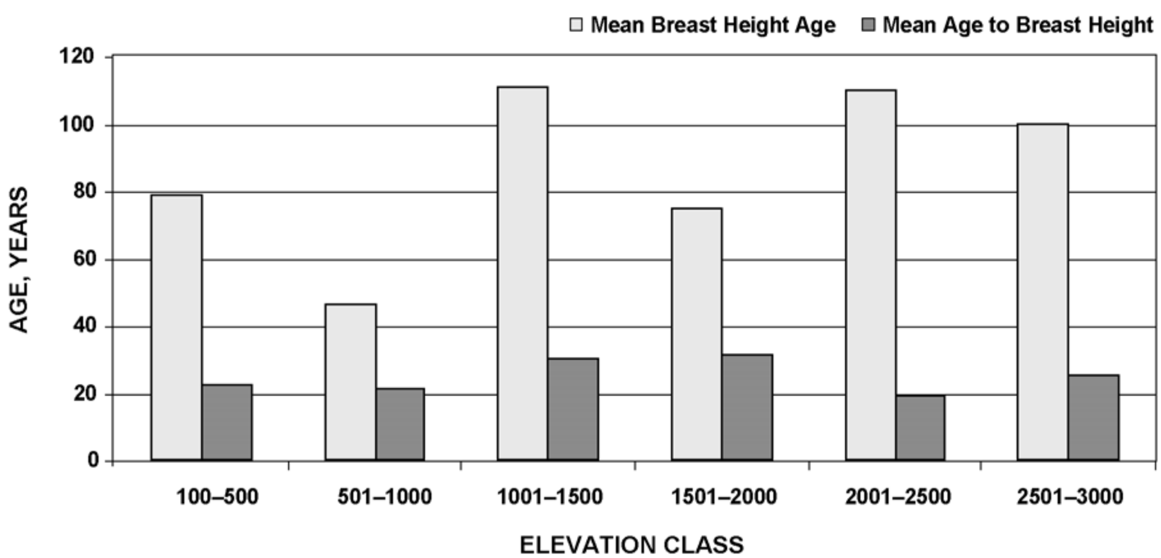

Figure 2.11. Mean breast-height ages and ages-to-breast-height for all felled trees.

Tessier (1954) reported that upland black spruce are shorter-lived than those in swamps because decay begins earlier and increases susceptibility to breakage. Here, however, older stands were found on upland sites. Table 2.12 presents a more detailed summary of age data.

Table 2.12. Age-to-breast-height summarized by elevation.

Elevation Class	Elevation, feet	Count	Breast-Height Age		Age-to-Breast-Height	
			Mean	Range	Mean	Range
1	100–500'	140	78	14–257	22	3–71
2	501–1000'	150	46	9–166	21	2–54
3	1001–1500'	188	110	13–222	30	5–119
4	1501–2000'	100	74	11–199	31	6–66
5	2001–2500'	35	109	65–161	19	5–43
6	2501–3000'	50	99	37–187	25	5–59

The oldest and youngest trees both grew at the lowest-elevation sites, but their growth rates were quite different. A tree with a breast-height age of 9 years was found at an elevation of 700 feet on the floodplain of the Chatanika River north of Fairbanks and took 43 years to reach breast height. A 257-year-old tree also grew on a floodplain, but at an elevation of 200 feet on the Tanana River near Delta Junction. It spent only 14 years reaching 4.5 feet in height. The lowest-elevation, slowest-growing tree was found at an elevation of 100 feet on the Kenai Peninsula; it took 48 years to reach breast height. The highest-elevation, fastest-growing tree grew at 3,000 feet, 20 miles northeast of Tetlin Junction in the uplands along the Taylor Highway; it took just 5 years to reach 4.5 feet and was 137 years old at that height.

These data present a “snapshot” of tree ages for a variety of aspects, elevations, site qualities, slopes, and stand densities across Alaska. Elevation is not the only state factor that governs the growth rate of black spruce. The wide spread of ages and growth rates summarized here should preclude generalizations about growth rates and ages relative to breast height and suggest only a poor correlation between age and elevation. Furthermore, the wide variety of site types supporting a wide variety of stand ages throughout Alaska suggests that the region-specific height-age (site index) model created here will be very useful for revealing more about the true range of productivity in this region of the boreal forest.

2.9 CONCLUSION

The polymorphic ite index curves presented here are the first for black spruce in Alaska. The model explained 94% of the variation in tree height. Use of these curves for trees up to 50 feet in height is believed to be suitable across Alaska and to be a vast improvement over the use of surrogate curves created elsewhere or for other tree species. In addition, breast-height ages for all trees sampled for site index and volume ranged from 9 to 257 years. Sample ages-to-breast-height ranged from 4 to 119 years.

Because they are polymorphic, these baseline estimates of productivity can be integrated with climatic, soil moisture, and soil nutrient variables and provide a bridge between empirical measurements of productivity and more theoretical ecosystem paradigms.

3 Height-Diameter Relationships of Black Spruce

3.1 INTRODUCTION

Accurate predictions of wood supply over time are critical to yield estimates for timber inventory and proper management of forest resources (Daniel et al. 1979, Peng 1999) including biomass, volume, and other parameters essential for describing stands. Estimation of the volume of merchantable wood fiber contained within standing trees is an essential element of any forest inventory. "Merchantable wood fiber" includes poles, house logs, sawlogs, pulpwood bolts, biomass, and fuel (Clutter et al. 1992). The height-diameter relationship is an important facet of forest stand structure (Peng 1999) that forms the basis for these estimates. Height and diameter account for the greatest proportion of the variability in tree volume (Avery and Burkhart 2002); they are used directly to quantify and predict tree growth (Davis et al. 2001) and to estimate the amount of wood fiber contained in tree stems. Height-diameter relationships can be used indirectly to guide silvicultural treatments and to assess the effects of various environmental factors on tree growth (Clyde and Titus 1987).

This chapter provides equations for calculating black spruce volume and height as well as information on height-diameter ratios, and stem taper.

3.1.1 Components of Tree Volume

An excurrent, or singular and well-defined, tree stem is a combination of paraboloid middle sections, a conical tip, and a neiloid stump. Total stem volume is the sum of the volumes of these shapes. Key dimensions include lengths (heights) and widths (Demaerschalk and Omule 1982) of each shape (Graves 1910, Husch 1963, Clutter et al. 1992).

Volume is a function of height and diameter; in forestry, stem taper and bark thickness are major components. Taper is the result of annual height accumulation (Clyde and Titus 1987); it varies among and within tree species and "cannot be ignored in the preparation of … volume tables (Kabzems 1953)." A tapered stem enables a tree to resist wind from any direction (Avery 1967). The sturdiness of the stem is quantified by dividing total height by breast-height diameter using equivalent units; e.g., height and diameter in feet (Smith et al. 1997). This is referred to as the height-diameter ratio.

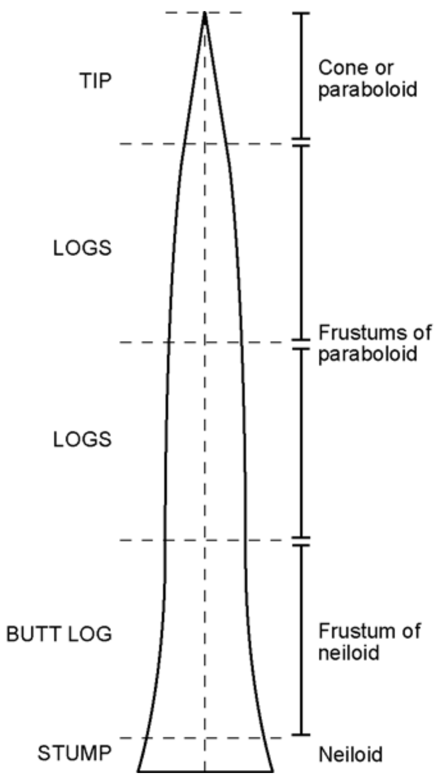

Figure 3.1. Tree stem geometry.

Figure 3.1 illustrates the geometry of a typical tapered stem. Trees growing in dense stands or understory positions, for example, taper little and have high height-diameter ratios (Savill et al. 1997) because diameter is more sensitive to loss of vigor than height (Smith et al. 1997). Dominant and/or open-grown trees have lower ratios but are more exposed to wind. Changes in stand density produce readily observable changes in these ratios (Savill et al. 1997). There is risk of blowdown in overcrowded stands if height-diameter ratios in the main canopy are greater than 100. A ratio of 70 or less is the goal in some managed spruce stands (Smith et al. 1997).

Accurate bark thickness estimates are especially important if bark has commercial value (Meyer 1946) such as fuel (Kozak and Yang 1981). Bark differs chemically from wood and varies physically more than wood due to its different cell structure and non-uniform surface (Hale 1955). Thickness varies by locality, as discovered by Kabzems (1953), who measured bark thickness of 390 Saskatchewan black spruce trees. “Different growing and especially different climatic conditions” explained why bark was thinner in Saskatchewan than that of trees growing in eastern Canada. Bark thickness also varies with species and at different points along a stem. The bark of ponderosa pine (*Pinus ponderosa* Laws.) and western larch (*Larix occidentalis* Nutt.) may be very thick on the trees’ lower portions and thinner nearer the crown; bark thickness of many hardwoods and thin-barked softwoods varies much less (James and Kozak 1984). “Bark thickness” must therefore be an average of several measurements (Graves 1910).

3.1.2 Direct Measurements of Volume

Volumes of irregularly shaped solids such as tree stems are most accurately estimated by measuring the volume of water displaced by the stem’s immersion in a xylometer (Bruce and Schumacher 1950, Maurer 1993). Cubic measures are a valid basis for derivation of all other measures of volume; because they are based on stem basal (cross-sectional) area and height (Daniel et al. 1979), cubic measures are accurate and practical for scientific purposes (Graves 1910) and entire-stem applications. “Log volume” is the product of its mean basal area and length along the stem.

Three formulas commonly used to calculate the volume of a paraboloid (Clutter et al. 1992) are:

Equation 3.1	$V = [(A_b + A_u)/2]h$	(Smalian)
Equation 3.2	$V = A_m h$	(Huber)
Equation 3.3	$V = [(A_b + 4A_m + A_u)/6]h$	(Newton)

where V = total cubic volume, h = log length or length between diameter measurements, A_b = basal area at base, A_m = median basal area, and A_u = basal area at top (uppermost diameter measurement). Diameter outside bark, or DOB (inches), is typically converted to basal area in square feet using $0.005454DOB^2$ (Avery and Burkhart 2002).

Each of these three formulas yields correct and identical results when log shape is truly parabolic. For other log shapes, Huber’s underestimates volume and Smalian’s overestimates (Husch 1963). Newton’s formula is most accurate for conoids or neiloids (Avery 1967, Wiant et al. 1992) but requires an additional midpoint diameter measurement. Smalian’s is preferred because it is easy to measure log lengths and the end diameters of cut logs or bolts during harvesting. Estimations of the volume of potential usable sawtimber in individual logs, made by measuring length and diameter and deducting for trim and defects (scaling) are calculated at log scaling sites or the mill (Bruce and Schumacher 1950). However, the lack of total height measurements and knowing which logs came from which tree negates the value of scaling data for determining tree volume and, hence, standing volume.

3.2 DEVELOPMENT OF METHODOLOGY

3.2.1 Volume and Form

Use of tree height and diameter to enumerate the amount of wood fiber in a stem is a classic mensurational challenge (Cunia 1964). The basis for volume prediction has historically been the relationship between stem content, DBH, height, and stem form. Here, volume is defined as the cubic-foot content of a single-stem tree. Emphasis is on single stems, meaning inclusion of only the dominant (tallest) stem. Non-dominant forks are excluded.

Stem form is commonly expressed as a ratio between the volume of a tapered stem and that of a solid of revolution, such as a cylinder (Husch 1963). The stem width measurement may be made at stump height or breast height; the height measurement is the total height of the tree. Knowledge of tree form is handy for estimating standing volume while cruising timber, but many prefer to omit the form variable from volume equations because, for most practical purposes, form variations have relatively little impact on volume. The form concept is not as straightforward as it seems because it varies considerably between and within tree species (Honer 1965). This strongly suggests that the use of white spruce volume and taper tables is inappropriate for black spruce. Another obstacle is the practical difficulty of making accurate upper-stem measurements without felling the tree (Honer 1965, Avery 1967, Clutter et al. 1992).

3.2.2 Harmonized Curves and Alignment Charts

Harmonized curves and alignment charts have also been used to construct volume tables (Honer 1965). Curves were “harmonized,” or redrawn without irregularities caused by sampling error (Bruce and Schumacher 1950) guided by knowledge that volume generally varies with the square of the diameter (Husch 1963). Harmonized curves required considerable skill and experience on the part of mensurationists (Honer 1965). Alignment charts graphically portrayed solutions to volume equations on logarithmic paper without plotting the actual curves; the basis for volume tables was a series of estimates read from the alignment chart (Bruce and Schumacher 1950). These estimates, along with the chart, were further modified to approach volumes derived from actual data (Husch 1963). The error potential in such subjective practices is obvious, but each provided reasonably accurate estimations of volume at the time. Later refinements of mathematical functions and more objective graphical methods became standard for describing the volume-height-diameter relationship (Honer 1965).

3.2.3 Commonly Used Volume Equations

Many region-specific or "local" volume equations can exist for a particular area. The four equations below illustrate common volume functions (Clutter et al. 1992). Any volume function should be accurate for all size classes, and error should be independent of tree size (Honer 1965):

Equation 3.4	$Y = b_0 + b_1 D^2H$	(combined variable)
Equation 3.5	$Y = b_0 + b_1 D^2 + b_2 H + b_3 D^2H$	(generalized combined variable)
Equation 3.6	$Y = b_1 D^{b2}H^{b3}$	(logarithmic)
Equation 3.7	$Y = D^2/(b_0 + b_1H^{-1})$	(Honer transformed variable)

where Y = stem content; D = DBH; H = tree height; and b_0, b_1, b_2, b_3 = constants.

3.2.4 Height-Diameter Functions

Newer volume equations rely heavily on accurate height-diameter functions derived with linear or nonlinear regressions of height on diameter (Yuancai and Parresol 2001) and/or site class (Maurer 1993). Height-diameter equations have superseded the exclusive use of tables to the point where a "volume table" signifies equations as well as tables (Avery and Burkhart 2002). Many height-diameter functions, such as those tested by Huang, Titus et al. (1992) and Peng (1999, 2001), are variations of "classical" equations (Yin et al. 2003) developed by Gompertz (1825), Weibull (1951), and Richards (1959). All are flexible and are commonly used to depict sigmoidal growth. Curves created with these equations are sigmoid, or *S*-shaped, and feature an upward-sweeping arc of rapid development followed by a gentle decrease in slope as growth rate tapers. Curves flatten at the top with the attainment of some asymptotic (maximum) size (Peng et al. 2001).

Creating height-diameter functions requires only field measurements of DBH, which saves time and money and makes destructive sampling unnecessary. The derived equation can be used to predict volume by substituting for the "height" variable in a volume equation (Maurer 1993) or be used to predict height growth when only DBH measurements are available (Huang et al. 1992). It can also be used to estimate individual tree biomass (Peng 1999), stand volume, and site quality (Yuancai and Parresol 2001). Good fit is essential because direct measurement of individual tree volume is not always possible (Reed and Harms 1956).

3.3 BLACK SPRUCE VOLUME

3.3.1 Previous Research

Work done by others on black spruce stem volume includes tree sizes similar to those found in interior Alaska; however, these still reflect local conditions. Most of the effort to derive volume information for black spruce has been concentrated in areas where it has commercial value. Brown (1928) published cubic-foot, inside- and outside-bark volume tables for Minnesota black spruce 30 to 65 feet tall and 3 to 12 inches DBH.

Other studies focused on black spruce in eastern Canada. Honer (1965) calculated cubic-foot volume for black spruce sampled “at various locations in Canada … accessible to the sampler.” Heights ranged from 10 to 90 feet and diameters from 2 to 20 inches. Honer used a transformed-variable function (Equation 3.7), to achieve homogeneity of variance without weighting the equation, and later used it to create metric timber tables for Ontario black spruce (Honer et al. 1983). This equation became a standard in Canada (Maurer 1993, Keys and McGrath 2002). Evert (1983) developed an equation for estimating individual-tree and stand volume for black spruce sampled from natural (vs. plantation) stands in Manitoba, New Brunswick, Ontario, and Quebec. Dimensions of the 785 trees felled for the study ranged from 9 to 82 feet and from 1 to 21 inches DBH.

Keys and McGrath (2002) compiled individual-tree volume tables for Nova Scotia softwood species based on Honer’s (1983) volume equation and included diameter correction factors for different species. In Saskatchewan, Kirby (1960) developed individual-tree volume and taper tables for 1,174 black spruce trees with heights of 37 to 74 feet and 4 to 14 inches DBH; 85% were between 4 and 6 inches DBH. This large study focused on the upper end of the range of sizes that this species attains. This lack of small (less than 30 feet in height) trees illustrates the need for information on the full range of sizes that black spruce attains.

3.3.2 Alaska Volume

Published volume tables for Alaska tree species have either inadequately included black spruce or ignored it altogether; height-diameter functions for Alaska black spruce are similarly nonexistent. Larson and Winterberger (1988) used stem analysis to create merchantable cubic-foot volume tables and equations for 244 white spruce and 44 black spruce in the Susitna River Valley of southcentral Alaska. The data were pooled, despite a sample bias of 6 to 1 in favor of white spruce, because analysis of covariance showed no significant differences between each species. They created a single equation to estimate volume for both species. The authors did not indicate where black spruce occurred in the range of sizes, but these tables are probably more accurate for larger trees due to the preponderance of sample trees taller than 30 feet, which is the minimum height listed in the published volume table. Additionally, the published equation has likely overestimated black spruce volume because the stems of this species have a greater rate of taper (Loso 1998). Gregory and Haack (1964) prepared volume tables for aspen, balsam poplar, paper birch, and white spruce in interior Alaska. There are no published volume or taper tables specific to Alaska black spruce; hence, degree of similarity of form is unknown.

When tree species are similar in form or grow in similar areas, volume measurements can be equivalent or proportional (Bélanger and Cléroux 1973). However, as Brown (1928) cautioned, “a volume table from one locality should never be applied to another locality before it has been checked against tree volumes obtained from the stands to be estimated.” Growth, and therefore volume estimates, for Alaska black spruce may be quite different because these trees experience greater seasonal light and temperature extremes (Oechel et al. 1985) and a shorter growing season than those in most other localities. The volume of wood fiber in stagnant stands of small black spruce trees common in interior Alaska may be comparable to the volumes of larger trees growing in stands that are more open. Hence, a clear need exists for individual-tree volume information specific to black spruce in Alaska.

3.4 FIELD METHODS

3.4.1 Stand Selection and Stem Analysis

In 2001 and 2002, 33 stands of the black spruce cover type as defined by Eyre (1980) were sampled in the Tanana Valley between Fairbanks and Northway (Figure 3.2; map created by the author). Using Eyre’s parameters, predominance of black spruce (at least 50% of the stocking) was the major criterion for stand selection; many stands were “pure” (at least 80% of the stocking). Stands selected for sampling were located on a variety of aspects, elevations, and slopes, and encompassed a full range of densities and crown classes. The objective was to include at least 10 stems for every height-diameter combination typical for black spruce; this translated to a minimum sample size of 600 to 900 trees. This was not always realistic in the field due to constraints such as lack of an extensive road system, time, and landowner permission.

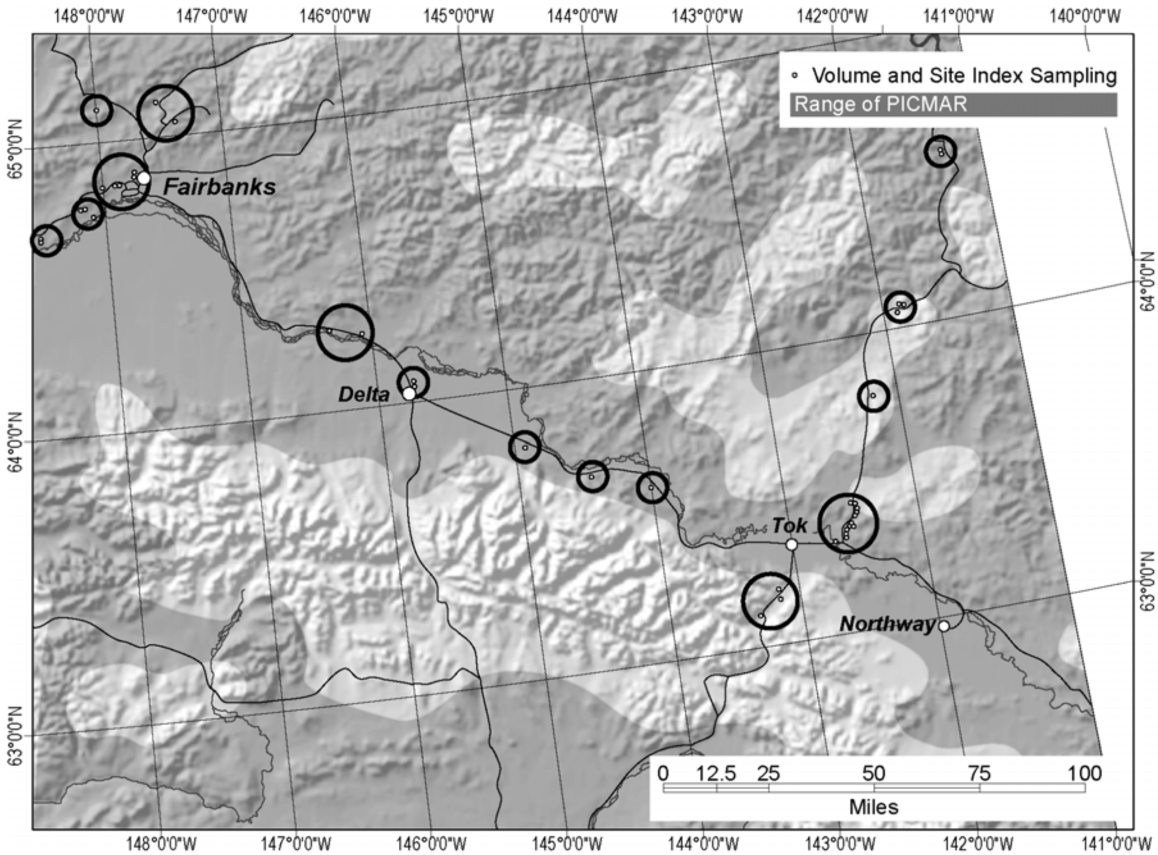

Figure 3.2. Stem analysis sites in the Tanana Valley.

Use of “target” trees and stands (purposive sampling) is a way to obtain adequate coverage of growing conditions and tree sizes over the range (Clutter et al. 1992) of black spruce in Alaska. Although destructive, stem analysis is considered justifiable if the product is a new equation Obvious data limitations are associated with inadequately sampling small and/or young trees and oversampling in mature stands. Samples that neglect to provide for variations in stand density can also result in a poorly fitting or unworkable model. Methods for avoiding such limitations include increased sampling, which averages out the effects of stand density (Maurer 1993). A robust sample size also aids in analysis, because variance of regression coefficients decreases with increases in the range of independent variables (Evert 1983).

Existing data from 200 trees felled for site index between 1984 and 1993 in southcentral Alaska, the Tanana Valley, and the Brooks Range were also included; total sample size was 1,071. Figure 2.1 shows site locations in these areas.

Plot size ranged from 0.5 to 1.0 acre; 25 to 50 trees at least 4.5 feet tall were sampled from each stand. Positive species identification was made by locating the reddish-colored pubescence on the current year's growth (Sargent 1933, Viereck and Little 1972). Crook, lean, and scarring defects were accepted if not excessive since they are typical of black spruce in Alaska. Forked tops were often concealed by dense clusters of cones and remained undiscovered until after the tree was felled. We rejected trees with forks longer than 2 or 3 feet.

Tree measurements included total height, stump height (0.5 feet from ground), diameter (to nearest 0.1 inch), DBH (diameter at 4.5 feet), and live crown length. Trees were marked at stump and breast height before felling. Once felled, trees were marked every 4.0 feet from breast height to the tip; if a top was forked, the largest fork was judged to represent the main stem (Larson and Winterberger 1988). Crown class, height, and live crown length were recorded on a standard field data sheet (Appendix J). Two 1.5 inch-thick stem sections were cut at 0.5 feet and 4.5 feet and marked with letters designating the tree; these were later used to determine years to breast height. Bags of disks were marked with the site number, location, and number of trees cut.

Bark thickness measurements were not made on most of the felled trees; bark thickness at breast height was measured for an independent sample of approximately 200 trees of all crown classes and sizes growing on a wide variety of sites. This was done to avoid sampling trees where bark was unintentionally removed during felling or measurement and could thus bias the sample. A bark gauge was used to take three measurements at breast height for each tree; each set of three measurements was then averaged.

3.5 CALCULATED DATA

3.5.1 Height-Diameter Ratio and Form Factor

Height-diameter ratios were calculated as:

Equation 3.8 $HDR = H / (DBH/12)$

where *HDR* = height-diameter ratio and *DBH* = stem diameter (in inches) (after Savill et al. 1997). Ratios were then summarized by crown class in Excel (Microsoft Corp. 2001).

Form factor was expressed as total tree volume relative to that of a cylinder:

Equation 3.9 $F = [VOB / (B*H)] * 100$

where *VOB* = total-stem, outside-bark volume calculated in Excel using Smalian's formula; *B* = stump basal area; and *H* = total tree height. The MEANS procedure (SAS Institute 2002) was used to generate summary statistics.

3.5.2 Bark Thickness Calculation and DIB Prediction

Because no bark thickness measurements had been taken on the felled trees, breast-height bark measurements made in 2002 on 200 independent trees were used to predict diameter inside bark (Kozak and Omule 1992) for all felled trees. Bark thickness can be predicted for individual sections based on stem diameter(Demaerschalk and Kozak 1977, Kozak and Omule 1992). DBHIB values for the independent trees were regressed on DBHOB (after Kozak and Yang 1981) using the REG procedure in SAS (SAS Institute 2002). This equation was then fitted to the entirety of diameter ouside bark (DOB) values to produce diameter inside bark (DIB) and, subsequently, basal area inside bark, and volume inside bark (VIB) values. The independent diameter and bark measurements functioned only to derive DIB and were not used in any other analyses. Finally, DIB values were used to calculate bark thickness for the sample using the standard equation (Husch 1963):

Equation 3.10 $$BARK = (DOB-DIB)/2$$

3.5.3 Volume Calculation

Model development began with direct calculation of tree volumes. Volume outside bark (VOB) for each 4.0-foot section was obtained using Huber's, Smalian's, and Newton's formulas to check for extreme volume-calculation differences. Differences were close to zero due to the short log length; values derived using Smalian's formula were chosen to represent calculated log volumes for each tree because of the relative ease of measuring the diameters of cut trees (Bruce and Schumacher 1950). Stump volume was calculated as the volume of a cylinder:

Equation 3.11 $$V_{stump} = H_{stump} * B_{stump}$$

where B_{stump} = basal area at 0.5 feet and H_{stump} = stump height (here, 0.5 feet).

Top volume was calculated as the volume of a cone with a height of the top section and a width of the uppermost basal area measurement (Avery 1967), as shown in Equation 3.12.

Equation 3.12 $$V_{top} = (B_{top} * (H - H_{top}))/3$$

where B_{top} = basal area at the topmost diameter measurement, H = total height, and H_{top} = height of the topmost diameter measurement. “Volume” equaled the sum of log, stump, and tip volumes.

3.5.4 Sample Size Distribution

The tabular distribution of sample heights and diameters (Table 3.1) at first appears to over-represent some of the smaller tree sizes. This reflects the character of the population of black spruce in Alaska. Most of the trees sampled between 1984 and 2001 are small; 46% were less than 25 feet tall and 60% were shorter than 30 feet. It was difficult to find a large number of trees taller than 45 to 50 feet.

Table 3.1. Height-diameter distribution of sample trees.

DBH → / Height ↓	0.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-11.9	Totals
76.5-80.4								1				1
72.5-76.4									1			1
68.5-72.4								1	1			2
64.5-68.4								2	4			6
60.5-64.4						2	5	1		1		9
56.5-60.4					1	5	4	3	5		2	20
52.5-56.4					1	3	6	6	2			18
48.5-52.4				1	1	12	7	5				26
44.5-48.4					5	15	9	1	2			32
40.5-44.4				2	25	20	16	5	2			70
36.5-40.4				10	38	23	10	3				84
32.5-36.4		1	6	34	34	17	6	2				100
28.5-32.4			21	49	29	5	6	1	2			113
24.5-28.4		7	40	45	13	5		1				111
20.5-24.4		21	63	22	4		1					111
16.5-20.4	12	83	31	1	1							128
12.5-16.4	47	64		1								112
8.5-12.4	81	1										82
4.5-8.4	45											45
Totals	185	177	161	165	152	107	70	32	19	1	2	1071

3.6 STATISTICAL ANALYSES

3.6.1 Height Prediction

The Chapman-Richards three-parameter function (Equation 3.13) was used to model the height-diameter relationship for Alaska black spruce:

Equation 3.13 $$H = 4.5 + a * (1 - e^{-b*DBH})^{c}$$

where H = total height; 4.5 = a constant used to account for measuring DBH at 4.5 feet above the ground; e = base of natural logarithms; DBH = outside-bark tree diameter at breast height (inches); and a, b, c = parameters to be estimated. The NLIN procedure (SAS Institute 2002) was used to solve for equation parameters and produce a height-diameter equation. NLIN uses an iterative process that depends on user-supplied starting values to estimate model parameters (Fang and Bailey 1998). The range of starting values was based on results obtained in another study of black spruce by Peng et al. (Peng et al. 2001).

3.6.2 Volume Prediction

Honer's (1983) transformed-variable function (Equation 3.14) was used to predict total-tree, inside- and outside-bark volume. This function is a proven and reliable predictor of volume (Maurer 1993, Keys and McGrath 2002). The NLIN procedure (SAS Institute 2002) was used to solve for equation parameters:

Equation 3.14 $$V = DBH^{2} / (a + b * H^{-1})$$

where H = measured total tree height (feet); DBH = outside-bark tree diameter at breast height (inches); and a, b, = parameters to be estimated.

3.7 RESULTS AND DISCUSSION

3.7.1 Range of Tree Sizes

Black spruce in Alaska attains sizes comparable to those in other parts of its range. Sample tree sizes ranged from 5.5 to 78.0 feet and from 0.4 to 11.0 inches DBH. Mean heights and diameters were 27.8 feet and 4.2 inches, respectively. The dimensions of the current largest black spruce tree in the United States are 78.7 feet tall and 19.7 inches DBH (American Forests 2003). The current Alaska champion was discovered in 2003; it is 70 feet tall, 14.5 inches DBH, and of unknown age. A tree almost as large was found in 2001 on a ridge top north of Fairbanks; it is also 70 feet tall and 14.4 inches DBH. It is 115 years old. Other large trees have been found in the Goldstream Valley north of Fairbanks. One specimen has a diameter of 19.4 inches, but its height cannot be accurately measured due to a broken top as well as severe crook and lean.[2]

3.7.2 Height Prediction Results

The Chapman-Richards height-diameter model converged quickly, but was run through the NLIN procedure several more times with different sets of starting values to ensure that the sum of squares obtained was a global, not local, minimum (Neter et al. 1996). None of the confidence intervals encompassed zero, indicating that all parameters were significant (p=0.05). Table 3.2 shows regression results.

Table 3.2. Results of nonlinear regression on height-diameter data.

The NLIN Procedure – Chapman-Richards Height-Diameter Function				
Parameter	Estimate	Approximate Standard Error	Approximate 95% Confidence Limits	
			Lower	Upper
a	91.2896	13.2965	65.1989	117.4
b	0.1050	0.0237	0.0585	0.1514
c	1.2894	0.0831	1.1264	1.4525

Summary Statistics					
Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	986179	328726	107461.0	<.0001
Residual	1068	32670.9	30.5907		
Uncorrected Total	1071	1018850			
(Corrected Total)	1070	190415			
R^2 = 1- (Residual SS / Corrected SS)	0.8284				
Chapman-Richards H-D Model	HEIGHT = H = $4.5 + 91.2896 * (1 - e^{-0.1050 * DBH})^{1.2894}$				

[2] Malone T. Personal communication.

3.7.3 Height Prediction Bias

Height prediction bias for the sample was calculated by subtracting predicted height from actual height. Positive numbers indicate over-prediction of height; negative numbers indicate under-prediction. Summary statistics were generated in Excel (Microsoft Corp. 2001). Mean prediction bias was -0.02 feet; standard deviation was 5.53 feet.

Table 3.3 shows prediction bias by 10-foot height class. Height class 70 has a range of 15 feet because only one tree was taller than 75 feet. This tree was included in height class 70.

Table 3.3. Height-prediction model bias by height class.

	Height Class, feet						
	10	20	30	40	50	60	70
Height Range, feet	5.0 – 15.0	15.1 – 25.0	25.1 – 35.0	35.1 – 45.0	45.1 – 55.0	55.1 – 65.0	65.1 – 80.0
Number of Trees	189	307	281	184	64	37	9
Mean Bias, feet	-1.06	-0.93	-1.96	0.73	5.15	10.93	15.99
Standard Deviation	1.58	3.67	5.80	5.35	4.85	6.68	5.54

Residuals were plotted in Excel (Microsoft Corp. 2001) against DBH (Figure 3.3) and measured height (Figure 3.4).

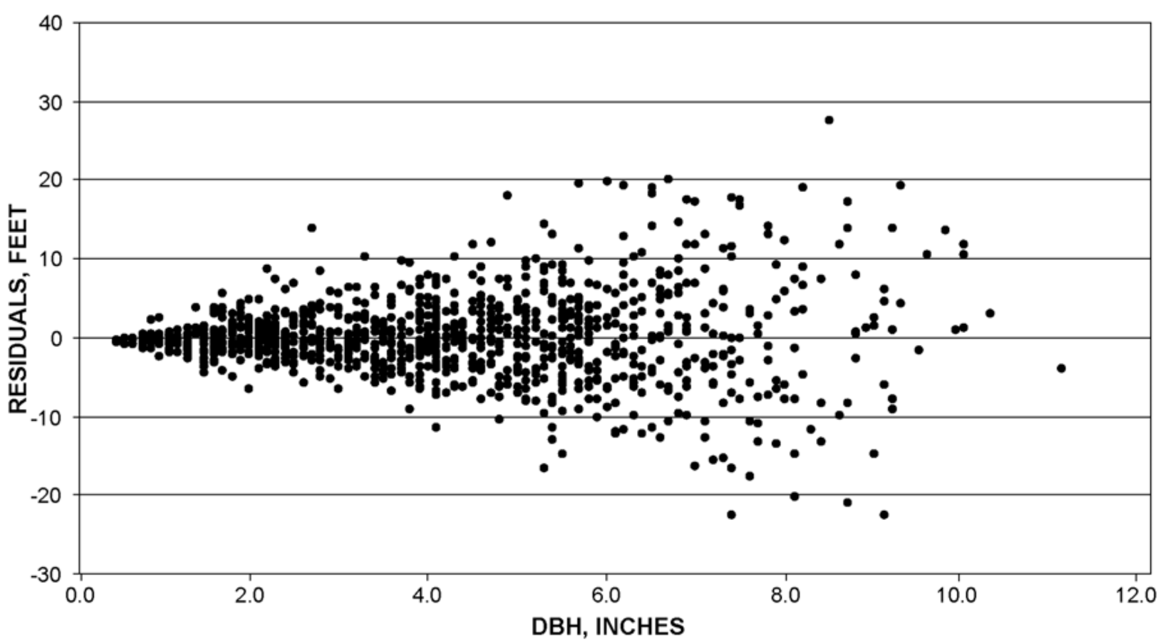

Figure 3.3. Residuals (actual height-predicted height) versus DBH.

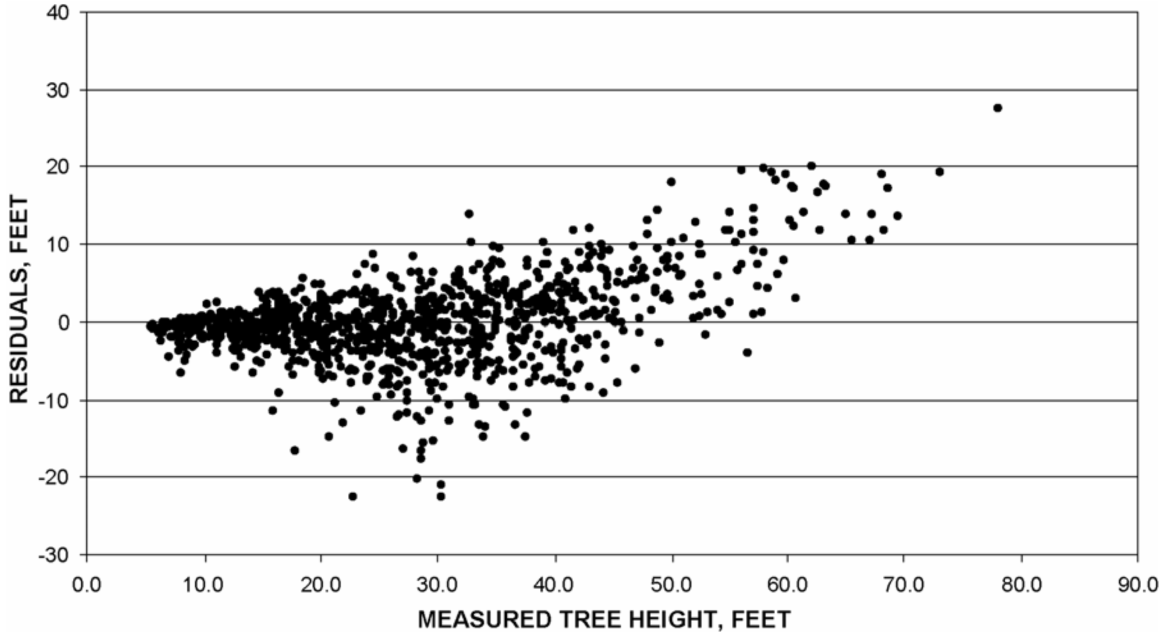

Figure 3.4. Residuals (actual height-predicted height) versus measured tree height.

The Chapman-Richards model appears to be a good predictor of black spruce height. Residual plots (Figure 3.3 and Figure 3.4) feature “clouds” of points about the mean up to breast-height diameters of 7.5 inches and heights of 50 feet. However, variance appears to increase for the larger tree sizes, possibly because relatively few large trees were found. This model could therefore be considered accurate for predicting tree heights up to 50 feet. The relatively few sample trees 50 feet and taller likely explains height overestimations of 5 to 16 feet (Table 3.3).

3.7.4 Volume Prediction Results

The Honer volume model quickly met convergence criteria. Parameter estimates were accepted after several more runs yielded identical results. Indications of good fit included low RMSE values and R^2 of almost 94% for VOB and VIB. Table 3.4 presents regression results.

Table 3.4. Final regression results for prediction of VOB and VIB.

<table>
<tr><td colspan="10">The NLIN Procedure - Honer Individual-Tree Volume Model</td></tr>
<tr><td colspan="5">Total Cubic-Foot Volume Outside Bark VOB</td><td colspan="5">Total Cubic-Foot Volume Inside Bark VIB</td></tr>
<tr><td colspan="2" rowspan="2">Parameter Estimate</td><td rowspan="2">Standard Error</td><td colspan="2">Approximate 95% Confidence Limits</td><td colspan="2" rowspan="2">Parameter Estimate</td><td rowspan="2">Standard Error</td><td colspan="2">Approximate 95% Confidence Limits</td></tr>
<tr><td>Lower</td><td>Upper</td><td>Lower</td><td>Upper</td></tr>
<tr><td>a</td><td>0.3450</td><td>0.1763</td><td>-0.00093</td><td>0.6910</td><td>a</td><td>0.2672</td><td>0.1846</td><td>-0.0950</td><td>0.6295</td></tr>
<tr><td>b</td><td>345.4</td><td>9.1769</td><td>327.4</td><td>363.4</td><td>b</td><td>355.8</td><td>9.6723</td><td>336.8</td><td>374.7</td></tr>
</table>

<table>
<tr><td colspan="6">Summary Statistics - Dependent Variable VOB</td><td colspan="6">Summary Statistics - Dependent Variable VIB</td></tr>
<tr><td>Source</td><td>DF</td><td>SSE</td><td>MSE</td><td>F Value</td><td>Pr > F</td><td>Source</td><td>DF</td><td>SSE</td><td>MSE</td><td>F Value</td><td>Pr > F</td></tr>
<tr><td>Regression</td><td>2</td><td>15576.1</td><td>7788.1</td><td>14340.2</td><td><.0001</td><td>Regression</td><td>2</td><td>10554.4</td><td>5277.2</td><td>13711.3</td><td><.0001</td></tr>
<tr><td>Residual</td><td>1069</td><td>580.6</td><td>0.5431</td><td></td><td></td><td>Residual</td><td>1069</td><td>411.4</td><td>0.3849</td><td></td><td></td></tr>
<tr><td>Uncorrected Total</td><td>1071</td><td>16156.7</td><td></td><td></td><td></td><td>Uncorrected Total</td><td>1071</td><td>10965.8</td><td></td><td></td><td></td></tr>
<tr><td>(Corrected Total)</td><td>1070</td><td>9632.6</td><td></td><td></td><td></td><td>(Corrected Total)</td><td>1070</td><td>6690.4</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">R² = 1/(Residual SS – Corrected SS)</td><td colspan="2">0.9397</td><td colspan="4">R² = 1/(Residual SS – Corrected SS)</td><td colspan="2">0.9385</td></tr>
</table>

3.7.5 Volume Prediction Bias

VOB prediction bias was calculated for the sample by subtracting predicted volume from actual volume. Positive numbers indicate over-prediction of height; negative numbers indicate under-prediction. Summary statistics were generated in Excel (Microsoft Corp. 2001). Mean prediction bias was 0.1209 ft^3; standard deviation was 0.7265 ft^3. Bias data were then stratified into 1-inch diameter classes and summarized (Table 3.5). Diameter class 10 has a range of 2 inches because only three trees were greater than 9.9 inches DBH (10.2, 11.0, 11.0 inches). These were therefore included in diameter class 10.

Table 3.5. Outside-bark volume prediction bias by diameter class.

	Diameter Class, inches									
	1	2	3	4	5	6	7	8	9	10
DBH Range	0.5-1.5	1.6-2.5	2.6-3.5	3.6-4.5	4.6-5.5	5.6-6.5	6.6-7.5	7.6-8.5	8.6-9.5	9.6-11.0
No. Trees	119	188	146	177	156	122	88	41	26	8
Mean Bias, ft^3	0.0391	0.1013	0.2484	0.2878	0.2483	0.1588	-0.0345	-0.6548	-0.1473	-0.7241
Std Deviation	0.0252	0.1235	0.3603	0.4664	0.7299	0.8117	1.1472	1.3677	1.6974	.2634

Residuals were plotted in Excel (Microsoft Corp. 2001) against measured tree height (Figure 3.5) and calculated VOB (Figure 3.6). In each plot, randomly scattered "clouds" of points about the mean indicate evidence of good fit.

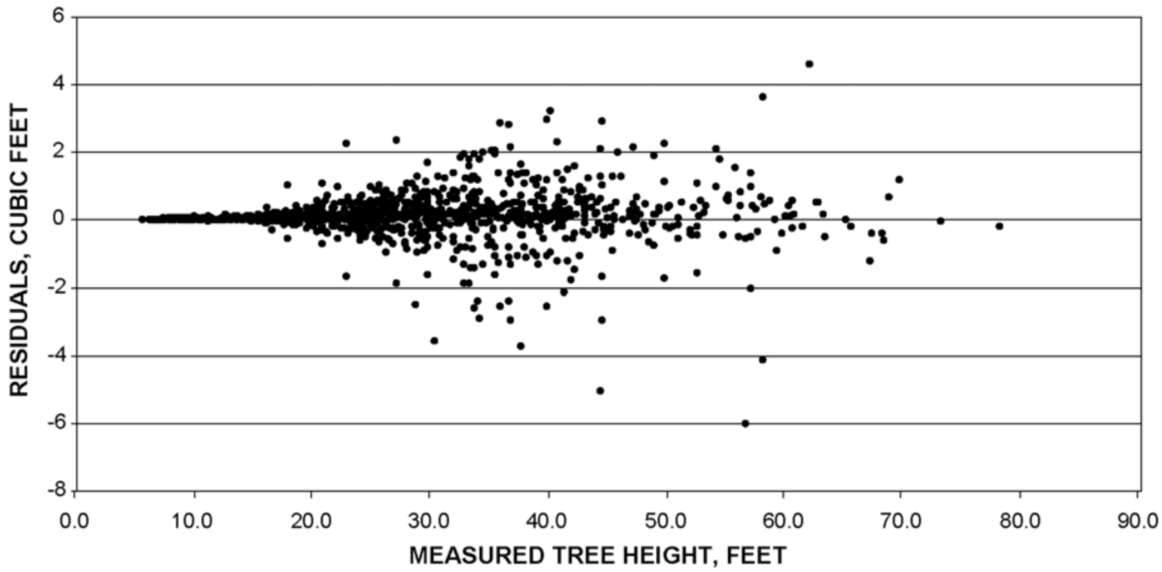

Figure 3.5. Residuals (actual volume-predicted volume) versus height.

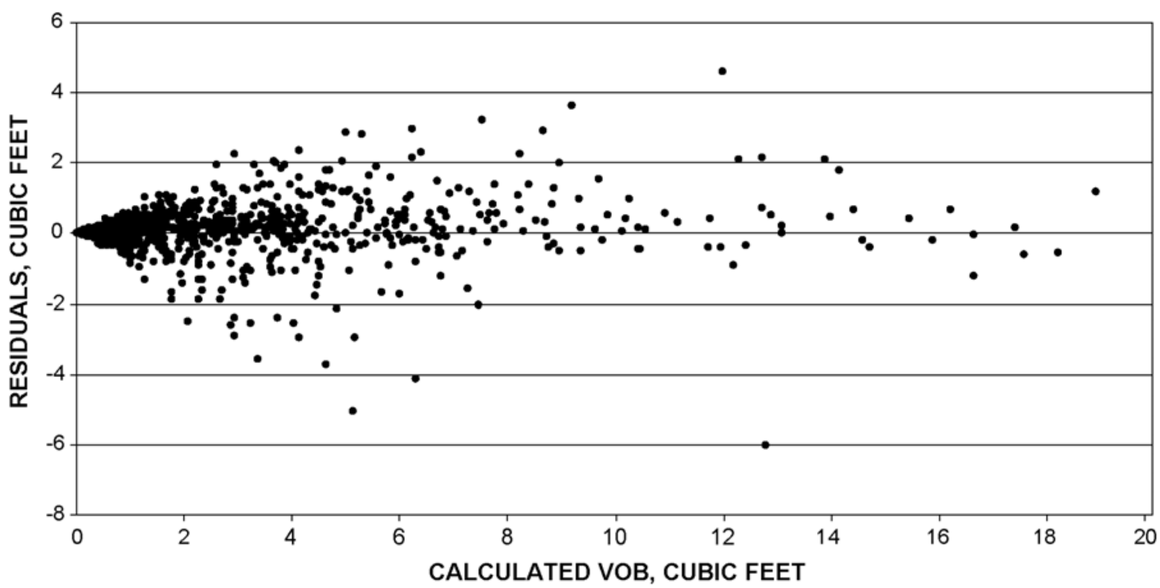

Figure 3.6. Residuals (actual volume-predicted volume) versus calculated VOB.

3.7.6 Final Height-Diameter Equations

Modeling height based on diameter is a facet of modern tree volume prediction (Yuancai and Parresol 2001) due to the relatively small investment involved in measuring only DBH and not total tree height (Fang and Bailey 1998, Peng et al. 2001). A new nonlinear, height-diameter function for Alaska black spruce was created (Equation 3.15):

Equation 3.15 $H = 4.5 + 91.2896 * (1 - e^{-0.1050*DBH})^{1.2894}$

Figure 3.7 shows the fitted curve and the height-diameter points that formed the basis for this DBH-based height prediction model.

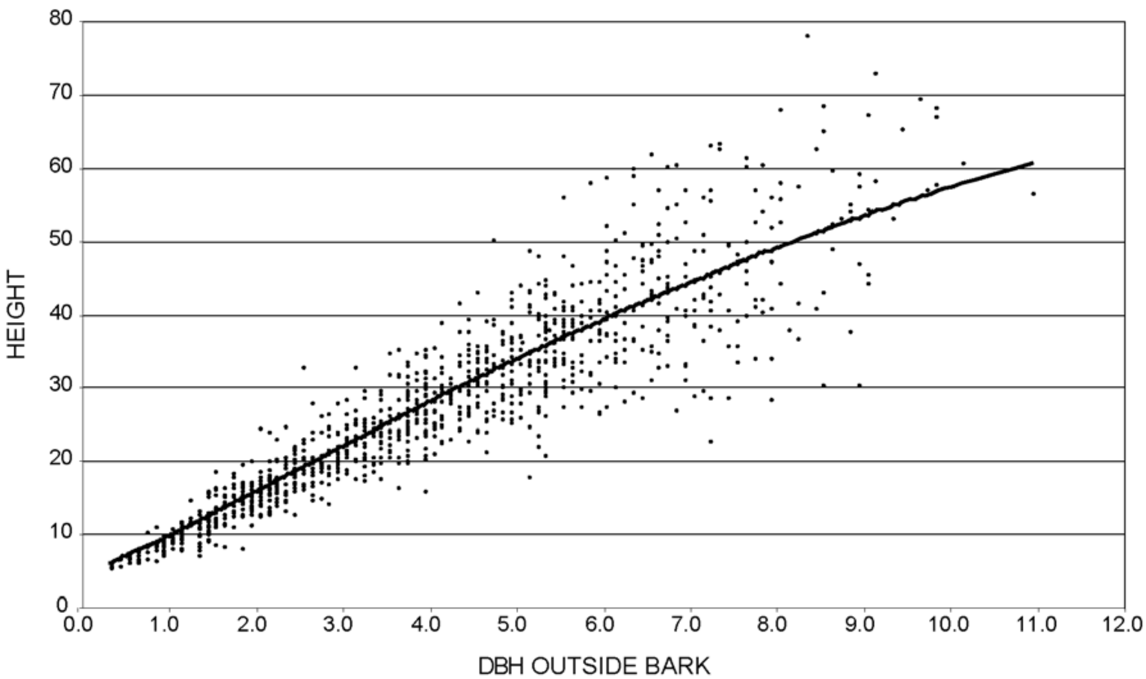

Figure 3.7. Chapman-Richards function fitted to height-diameter data.

New VOB (Equation 3.16) and VIB (Equation 3.17) equations were derived using the Honer's standard individual-tree volume function. They are based on DBH and predicted height, including the stump and top, and do not account for decay (we estimate that less than 5% of felled trees were rotten at the stump). Bark accounts for ±19% of the total volume of the sample.

Equation 3.16 $VOB = DBH_{OB}^2 / [(0.3450 + (345.4 * H^{-1})]$

Equation 3.17 $VIB = DBH_{IB}^2 / [(0.2672 + (355.8 * H^{-1})]$

Tree volume and breast-height diameters were plotted in Excel (Microsoft Corp. 2001) for VOB (Figure 3.8) and VIB (Figure 3.9):

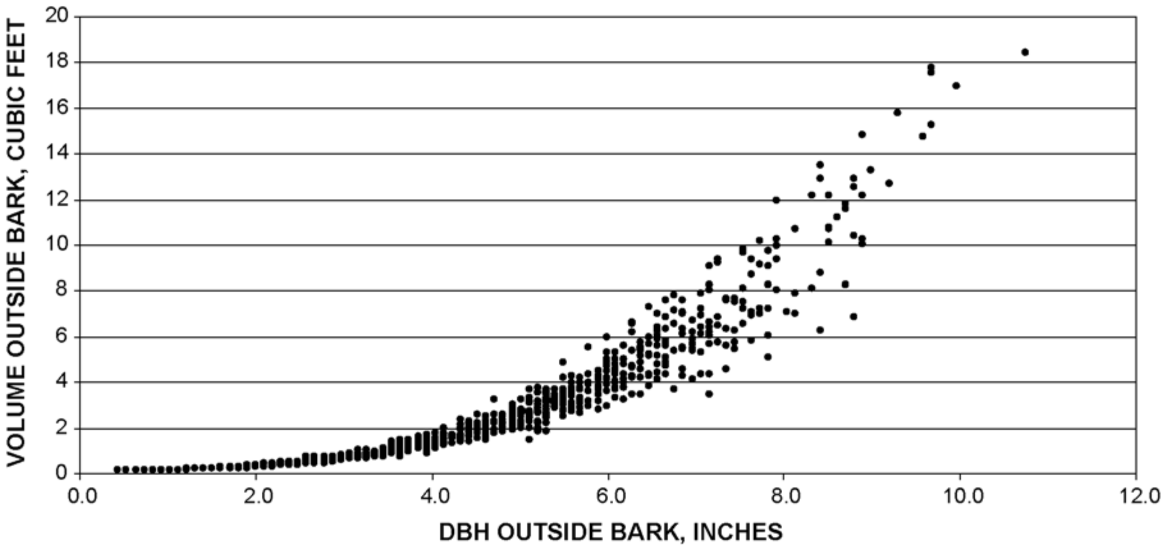

Figure 3.8. Predicted VOB versus DBH (outside bark).

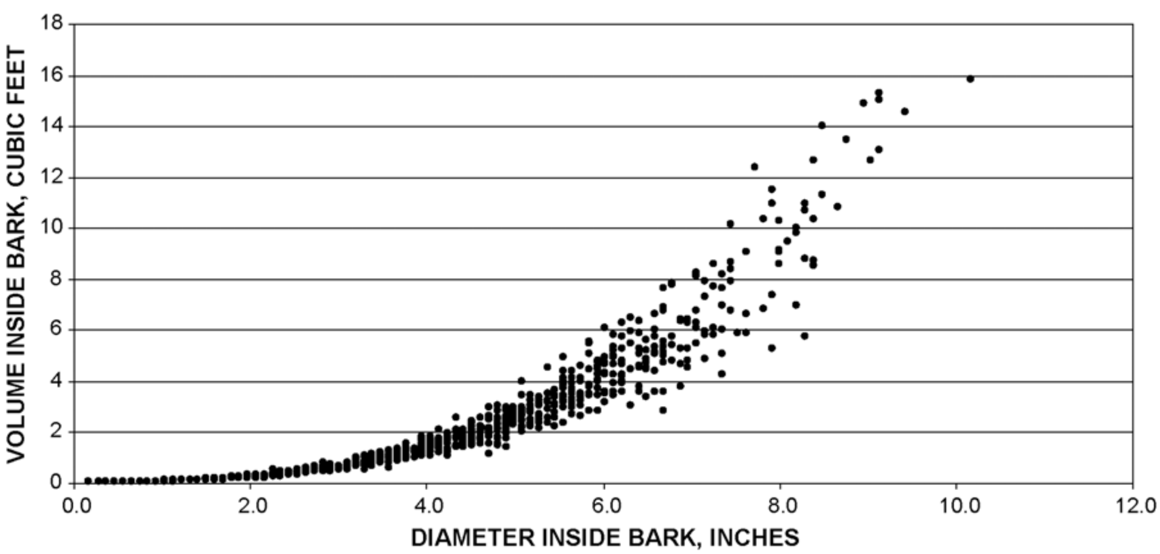

Figure 3.9. Predicted VIB versus DBH (inside bark).

3.7.7 Stem Form Results

Height-diameter ratios are summarized by crown class in Table 3.6 to assess the potential for blowdown. High ratio values indicate a consistently high rate of stem taper across crown classes. Lower numbers indicate more windfirm trees. As height-diameter ratios approach the “blowdown” threshold of 100, any management would dictate careful thinning to guard against loss of entire stands due to wind (Smith et al. 1997).

Table 3.6. Height-diameter ratios.

Crown Class	Count	Mean	Standard Deviation	25th Quartile	75th Quartile
Dominant	521	81.1	15.10	71.4	90.5
Codominant	288	83.4	16.54	73.0	91.8
Intermediate	251	93.0	18.93	80.5	103.2

Taper was calculated as stem volume relative to the volume of a cylinder of the same basal (stump) width and height. High height-diameter ratios and taper (form factor) values indicate a high potential for blowdown in Alaska black spruce. Stem volumes ranged from 33% to 45% of those of cylinders of equal size. Minimum form factors remain consistent across height classes, but maximum form factors have a much wider range (38–94), indicating that sample trees came from a variety of stand densities. Overall, stem taper appears to increase with tree height. Table 3.7 summarizes form factors for the sample.

Table 3.7. Form factors by height class.

Height Class	Height, feet	Number of Trees	Mean Tree Form (%)	Standard Deviation	Minimum	Maximum
10	5.0 – 15.0	189	45	9.3	27	94
20	15.1 – 25.0	307	40	10.3	22	97
30	25.1 – 35.0	281	37	9.2	20	78
40	35.1 – 45.0	184	35	6.1	23	55
50	45.1 – 55.0	64	34	4.5	25	44
60	55.1 – 65.0	37	33	5.4	22	46
70	65.1 – 80.0	9	34	3.5	29	38

3.8 CONCLUSION

Stem analysis of more than 1,000 black spruce trees and unweighted, nonlinear least-squares regression procedures were used to create new equations that predict total height and total cubic-foot, individual-tree volume for black spruce. Predicted heights ranged from 6.5 to 14.6 feet for trees up to 1.5 inches DBH. Predicted heights for trees 10.5 to 11.5 inches DBH ranged from 60.5 to 63.6 feet. The model explained 83% of the variance in tree height. This model is accurate for predicting heights for black spruce up to 50 feet tall, but should be used with caution when predicting heights of larger trees.

Predicted total-tree, outside-bark volumes ranged from 0.0156 ft^3 to 0.2298 ft^3 for trees up to 1.5 inches DBH. Predicted total-tree, outside-bark volumes for trees 10.5 to 11.5 inches DBH ranged from 12.8 ft^3 to 18.2 ft^3. The Honer volume equation explained 94% of the variation in tree volume. Measures of stem taper (form factors) and height-diameter ratios were calculated and summarized.

The information presented here sheds light on height- and diameter-growth patterns of black spruce north of 60° latitude in Alaska, and can serve as a foundation for future work.

4 Stand Characterization

4.1 INTRODUCTION

A major objective of this research was to summarize the growth characteristics of black spruce in Alaska. Sound forest management requires possession of discrete stand information based on inventory data (Nyland 1996). The physiographic ecology of black spruce has been studied, but relatively little work has been done to summarize growth characteristics in the even-aged, mid-seral stands (Krestov et al. 2000) that are prevalent — along with overmature, multi-cohort stands — across Alaska. Information about stand densities, diameters, heights, and volumes for the sizes that black spruce commonly attains in interior Alaska are included here to complement the height- and volume- prediction functions created for individual trees.

A limited number of Permanent Sample Plots (PSPs) were established as part of the UAF Forest Growth and Yield Program (Packee 2003) and provide a basis for summarization and expansion of individual plot measurements to the stand, or per-acre, level. The species and relative abundance of vascular and non-vascular plants found at these plots are also listed in order to present a general idea of the variety of site types on which black spruce occurs in Alaska. Physiographic features are summarized for all sites. Finally, existing pedon descriptions are included for selected sites throughout the study area.

4.2 DEVELOPMENT OF METHODOLOGY

4.2.1 Vegetation Communities

Nichols (1917) considered groups of plants to be "associated" if they occupied a common habitat (environment). He created and emphasized a precise climatic, edaphic, and biotic definition of "habitat." Climatic factors are comprised of atmospheric humidity, precipitation, temperature, and light. Edaphic factors include soil chemistry and hydrology, as well as patterns of erosion and deposition governed by slope. "Local climate" for a steep, south-facing slope, for example, differs markedly from the "local climate" for a gently sloping northern aspect. Soil moisture is “probably the most important determinant of growth”; variations in vegetation directly reflect variations in below-ground moisture (Rowe 1956). Biotic factors include the effects of other species on a particular habitat. One important example of the influence of a biotic factor in the boreal forest is the amount of understory shading from dominant plants, which inhibits development of shade-intolerant species and changes the evaporative power of the air.

Plant understory species have long been used to indicate site conditions for tree growth (Corns and Pluth 1984). Cajander (1926) was among the first to use floristic compositions defined by understory interspecies competition to classify “forest types” independently of tree species. Forest type classifications are useful in northern and western forests due to the presence of a relatively smaller variety of vegetation, which lends distinction and ease of identification to vegetative communities. Disturbance is also less frequent (Avery and Burkhart 2002). Knowledge of understory plant associations can be used to interpret successional trends as the growth of overstory plants over time reduces the amount of light falling on the forest floor. Assessments can also be made of site quality and the likelihood of regeneration. Plant classifications should augment climatic, edaphic, and biotic factors because these factors “are not necessarily more reliable or easier to interpret than the flora”. Soil profiles, especially, require “considerable back-breaking work” before they can be examined (Rowe 1956).

New boreal plant community classifications based on ordination and multivariate analyses are beyond the scope of this research. Indeed, Pojar (1996) considers existing, broad-scale ecological zonations developed for the western boreal forest (defined as the area from Manitoba west through Alaska) to be applicable in forestry because they reflect latitudinal and physiographic changes, yet tend to remain consistent at the site level. This has held true since Rowe (1956) created vegetation classifications based on five levels of soil moisture for western boreal spruce forests of Manitoba and Saskatchewan. Rowe also emphasized the ease of applicability of a generalized descriptive scheme for forestry application.

4.2.2 Stand Density

Black spruce, like other tree species, has an upper limit to the number of trees that will fit on an area of land before excessive mortality occurs. Absolute density measures such as trees per acre provide little information about stocking or competition; a count of 600 saplings per acre differs greatly from an equal number of sawlog-sized trees (Anhold et al. 1996). A stand density index (SDI) is a way to measure the degree of crowding using easily measured tree attributes such as numbers of trees, basal area, or average diameter per unit area. SDI is based on Reineke's (1933) discovery that any two pure, even-aged stands with equivalent average stand diameters will have approximately the same number of stems per acre.

SDI is independent of site quality and tree age, and provides more information about a stand than does "stocking," which simply defines the proportion of an area actually occupied by trees (Nyland 1996). Expressed as a number of trees, SDI can be used to define the upper limit of stocking in a stand (Daniel et al. 1979). Low stocking means faster individual tree growth at the expense of fiber quality and volume per unit area. Dense stocking slows tree growth and results in better fiber quality and more total and merchantable wood volume per unit area.

Density management means the acceptance of a compromise between maximum volume production and maximizing vigor of individual trees (Nyland 1996). SDI shows how a managed stand is performing relative to specified goals (Davis et al. 2001). Stand thinning can control competition, maintain the vigor of the best-growing trees, or capture mortality before it occurs. Benefits of density management include predictability of growth and future yield, as the managed stand takes shape according to objectives such as disease prevention, hazard reduction, timber production, and wildlife habitat (Nyland 1996).

4.2.3 Stand Volume

Individual tree volumes are commonly determined from section diameters and total tree lengths. Standing tree volumes are estimated from measurements of DBH and total tree height (Evert and Lowry 1971). Stand volumes may be safely estimated from summed basal areas and mean heights, because stand volume is the sum of individual tree volumes (Evert and Lowry 1971). Furthermore, conventional timber-cruising methods are expensive and inefficient for dense stands that contain small, low-value trees (Parent 2003). Remote sensing and geographic information system (GIS) techniques can be used to classify or estimate aspects of strata or stands. PSPs can then be used to check, or "ground-truth," the remotely sensed strata. Forest stand data collected from PSPs can also be used to develop stand volume equations. Here, calculations of the volume of wood fiber present in the often dense, small-diameter stands of black spruce in Alaska can be useful for forest management activities.

4.3 FIELD METHODS

4.3.1 PSP Location and Establishment

In 2002, 60 PSPs were established in 20 black spruce stands in the Tanana Valley between Fairbanks and Northway. All sites were road-accessible and occurred on ridge tops, slopes, river terraces, and valley bottoms. Most stands were located within the Tanana Valley State Forest; others were on land owned by the Native village corporations of Tetlin and Northway, the U.S. Department of Defense, and the Fairbanks North Star Borough. Attainment of landowner permission was a major constraint. However, permission was relatively easy to obtain because of the relatively small amount of land necessary (less than 10 acres) and the fact that no destructive sampling occurred. Figure 4.1 shows PSP locations (map created by the author).

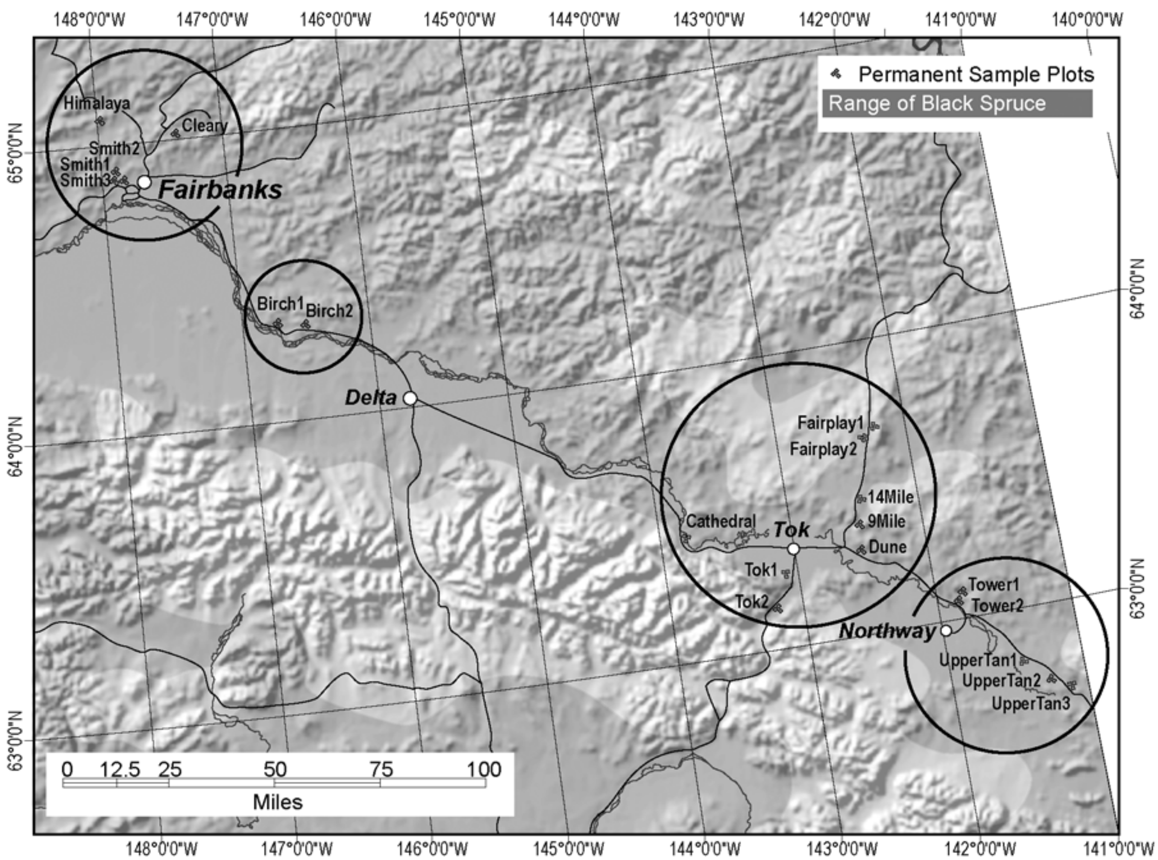

Figure 4.1. PSP locations in the Tanana Valley.

A plot size of 0.1 acre is considered standard in forestry (Rowe 1956). Figure 4.2 (a) (graphic created by the author) illustrates plot orientation. The location of the northwest corner of the first plot was randomly selected from within the permitted area by walking approximately 150 feet from the road edge and tossing a metal stake into the stand. The stake was inserted into the ground and flagged. Plot numbers were marked on flagging attached to the nearest tree. Positions for the remaining corner stakes were located with compass and measuring tape to ensure a square plot that was 66 feet per side. Physical features of some sites (e.g., a black spruce stand on a narrow strip of ground bordered by a road or different cover type) dictated plot placement along a transect instead of in a triangular pattern. Plot center was located, staked, and flagged, and its geographic position recorded with a GPS unit. The corners of the remaining two plots were located 100 feet north or east from one corner of the first plot. Finally, the trees forming the plot border were marked with a paint stick to ensure that only trees within the plot would be measured. All plots were located and marked in this manner to ensure successful relocation. Metal stakes were used so that they could be relocated with a metal detector.

4.3.2 Plot Measurements

PSPs are most effective for sampling forest growth when measurements follow a standard protocol (Guarnaccia 1961). In this study, data collection and measurement procedures were consistent with those of the UAF Forest Growth and Yield Program (Packee 2003). Physiographic site data were recorded on a standard field data sheet (Appendix J). Features included aspect, slope, likelihood of permafrost, slope position and contour, landform, and soil parent material. A photograph taken from the northwest corner of each plot provided a record of the plot’s appearance at the time of establishment. Soil pits were dug at each site and a general description of soil color, moisture, texture, and horizon thickness was made. Features such as charcoal and volcanic ash were also recorded.

Tree measurement began at the northwest corner of each plot and progressed in an east-west direction, as illustrated in Figure 4.2 (b). Each tree larger than 0.55 inches DBH was designated with a numbered metal tag through which wire had been threaded. The tag-wire combination was then inserted into the ground on the east side of the base of each tree. This was considered a relatively permanent way to mark trees without damage to the tree.

Standardized measurements included height (total length of stem), diameter (outside bark to nearest 0.1 inch), breast height (4.5 feet from ground), and live crown length (to nearest foot, starting at height of lowest large vigorous branch). Total height was determined to the nearest foot using a calibrated measuring stick for trees 16 feet or less in height; a laser rangefinder was used to determine heights of taller trees. Breast height was determined with a 4.5-foot pole held next to the stem. Where trees grew on sloping ground, the pole was placed on the uphill side of the tree. A numerical code system was used to record tree species, crown class, and the location, type, and extent of damage to any part of the tree. Damage included broken tops, butt swell, chlorosis, crook, excessive lean, fire scars, insect damage, multiple tops, and spruce-rust brooms.

Figure 4.2 (c) illustrates regeneration subplots. Five circular, 1/250th-acre plots were located within each PSP to count and describe regeneration by height class, species, and vigor. Height classes included stems less than 6 inches tall, stems between 6 inches and 4.5 feet tall, and stems greater than 4.5 feet tall but less than 0.55 inches DBH. Degree of canopy closure was measured at each subplot using a crown densiometer. Stand age estimates were obtained by coring a representative of each tree species found growing just outside plot perimeters. It was not always possible to find a representative of each crown class for each species in the vicinity.

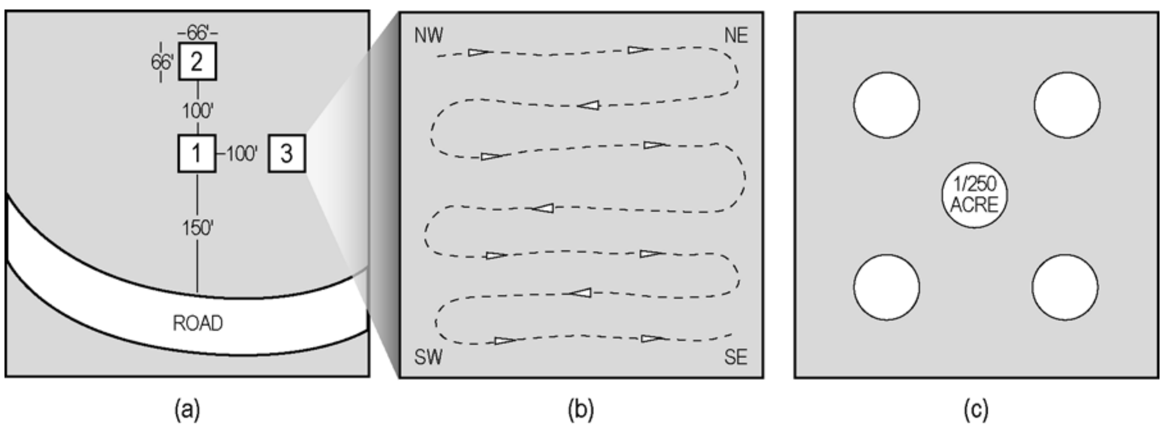

Figure 4.2. PSP orientation and establishment.

Vegetation was listed by species and cover class. Cover classes were based on a scale created by Daubenmire (1968) to make general estimations of species cover without regard to species overlap. Cover classes are by percent, i.e., Trace=T (<1.0%); 1=1–5%; 2=5–25%; 3=25–50%; 4=50–75%; 5=75–95%; 6=95–100%. The “Trace” category was provided so as not to over-represent instances of a single or few individuals on a site. Cover estimates were also made of dead wood, forest litter, and mineral soil.

The expense of establishing PSPs makes it essential that they remain as free as possible from human-caused disturbance until at least one five-year remeasurement interval has elapsed. However, the risk of natural disturbances, such as flooding or wildland fire, is accepted. In 2004, fires consumed several PSPs established in 2002 at sites on the Taylor Highway. Remeasurement will occur as scheduled and will be a unique opportunity for first-hand observation of forest succession resulting from natural disturbance.

4.3.3 Soils

Concurrent with this research, some sites were revisited by Ping et al. (2004) who dug deeper and larger soil pits and compiled detailed descriptions following protocols outlined in the USDA Soil Survey Manual (Soil Survey Division Staff 1993). To date, soils have been fully described at sites as shown in Figure 4.3 (map created by the author). Appendix I lists physiographic information and pedon descriptions for these sites.

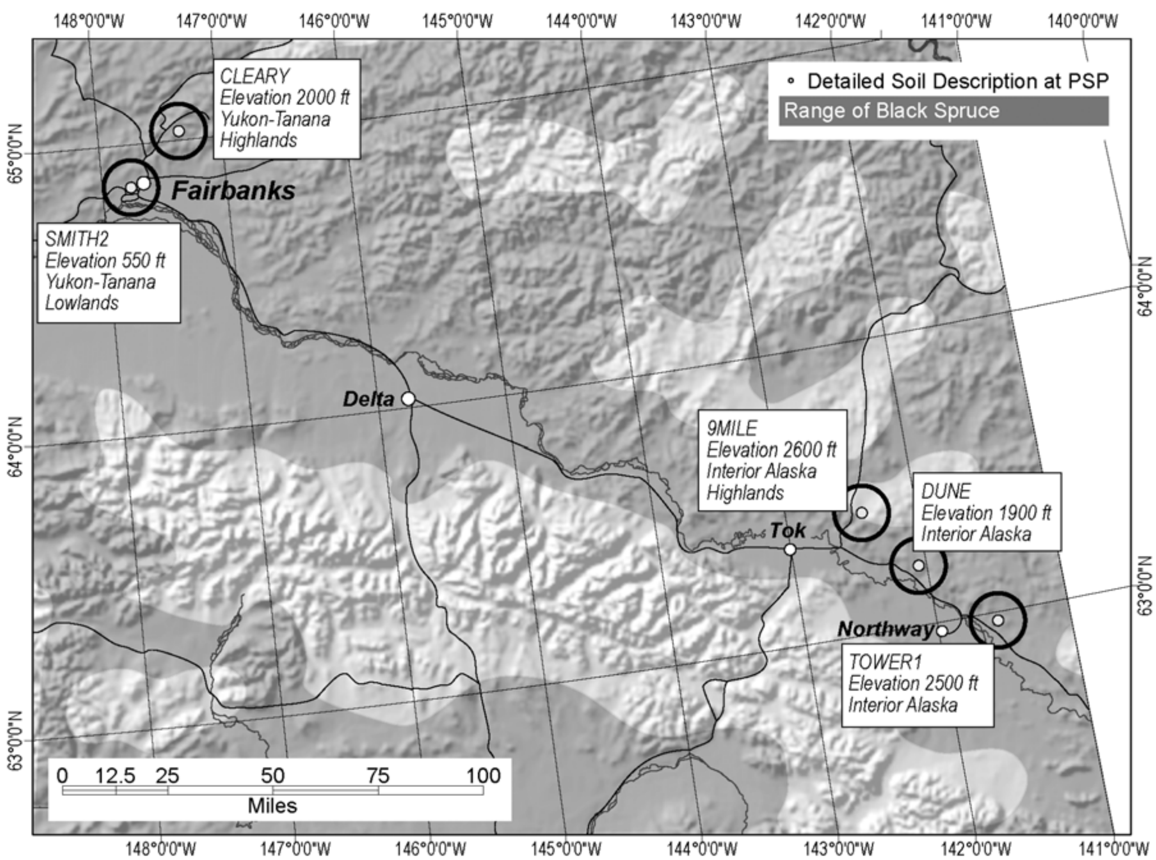

Figure 4.3. PSP sites with detailed soil pedon descriptions.

4.3.4 Associated Vegetation

Appendix D summarizes vascular plants found at each PSP by site, cover class, and species; Appendix E summarizes non-vascular plants. Bryophytes received special attention because they are such a dominant feature of black spruce stands. The objective was a general identification and estimate of importance (percent cover by species). The limited number of sites sampled did not permit valid development of a community classification system or ordination.

4.4 CALCULATED DATA

Data were entered into Excel (Microsoft Corp. 2001) spreadsheets, checked for errors, and summarized by plot and site. GPS coordinates of plot locations were differentially corrected to increase their accuracy, and overlaid on topographic maps using ArcGIS (Environmental Systems Research Incorporated (ESRI) 2004). “Stand measurements” refer to the combined measurements of the three PSPs established at each site. Key calculations include trees per stand, stand basal area, mean stand height, and mean stand diameter, and stand volume, and stand density index. Selected stand measurements were then expanded from the site level to the per-acre level by multiplying the combined 0.3 acre by 3.3. Expanded stand measurements include trees per acre, basal area per acre, and volume per acre.

4.4.1 Stand Calculations

“Trees per stand” was calculated for each site as the sum of all species of trees greater than 0.55 inches DBH. Stand basal area was calculated as the sum of individual tree basal areas:

Equation 4.1 $$B_s = 0.005454 * \sum D_i^2$$

where B_s = stand basal area and D_i = DBH of each tree (Davis et al. 2001). Stand basal area is a key component in designing thinning regimes (Avery and Burkhart 2002).

Mean stand height is a useful measure of stand height in even-aged stands. However, a weighted-mean method is often sought because larger trees contribute more to mean stand height. Equation 4.2 illustrates Lorey’s formula:

Equation 4.2 $$H_L = \sum (H_i * B_i) / \sum B_s$$

where H_L = Lorey's mean height; H_i = individual-tree height; B_i = individual tree basal area; and B_s = stand basal area. Lorey's height is considered more stable than an unweighted mean height because it is less affected by mortality and harvesting of smaller trees (Brack 2002).

Quadratic mean stand diameter was calculated to obtain the diameter of a tree of mean basal area:

Equation 4.3 $$D_Q = (\sum D_i^2 / n)^{½}$$

where D_Q = quadratic mean diameter, D_i = DBH of each tree, and n = number of trees in the stand. A stronger correlation exists between stand volume and quadratic mean diameter than between stand volume and arithmetic mean diameter. Mean values may be used with estimates of the number of trees per acre to determine the level of competition within a stand (Brack 2002).

4.4.2 Stand Volume and Volume per Acre

Total cubic-foot volume was calculated for each tree using the individual-tree, outside-bark volume function developed in Chapter 3:

Equation 4.4 $$V = D^2 / [(0.3450 + (345.4 * H^{-1})]$$

where V = stand volume (cubic feet), D = DBH (outside bark, inches), and H = total height (feet). Stand volume was calculated as the sum of individual-tree volumes for each stand. Volume per acre was calculated by multiplying stand (site) volume values by 3.3.

4.4.3 Stand Density Index

Stand density (stems per acre) was calculated for each site by multiplying the number of stems per stand by 3.3. Stems per acre are of limited value in natural stands, but many silvicultural prescriptions are made for plantations (Avery and Burkhart 2002) and could be useful in artificial regeneration efforts or for developing thinning guidelines.

Stems-per-acre measurements were used along with stand basal area measurements to construct a stand density index (SDI) for each site. SDI was calculated as:

Equation 4.5 $$SDI = (D_Q/10)^{1.605} * TPA$$

where D_Q = quadratic mean diameter and TPA = trees per acre (Reineke 1933).

RESULTS AND DISCUSSION

Table 4.1 shows stand summaries for each of the 20 sites. Appendix C summarizes specific physiographic features found at each site. Bark accounts for ±19% of the total volume of the sample.

Table 4.1. Stand information by site (three plots per site).

Site Name - Number	Trees per Site	Lorey's Mean Height	D_Q, in	SDI	Stand BA, ft^2	Stand VOB, ft^3	Trees per Acre	Volume per Acre, ft^3
Birch1 – 1	63	13.42	1.94	15	1.29	9.08	210	29.96
Birch2 – 2	318	24.83	3.39	186	19.90	255.32	1060	842.57
Tok1 – 3	517	20.84	2.62	201	19.35	209.38	1723	690.94
Smith1 – 4	676	19.66	2.16	193	17.25	175.90	2253	580.47
Smith2 – 5	503	37.73	3.42	299	32.02	614.00	1677	2026.19
Himalaya – 6	325	36.91	3.98	247	28.05	528.09	1083	1742.68
Cleary – 7	205	15.78	2.66	82	7.92	65.25	683	215.31
9Mile – 8	400	36.85	4.26	340	39.67	746.54	1333	2463.59
Fairplay1 – 9	41	10.62	1.43	6	0.46	2.54	137	8.40
14Mile – 10	324	20.14	3.14	168	17.41	182.25	1080	601.43
Fairplay2 – 11	135	12.93	1.81	29	2.40	16.24	450	53.59
Tok2 – 12	512	20.57	1.96	125	10.76	114.81	1707	378.89
Dune – 13	872	24.43	3.14	453	46.88	759.63	2907	2506.79
Smith3 – 14	567	25.96	2.52	206	19.58	262.15	1890	865.09
Cathedral – 15	529	13.66	1.99	133	11.51	82.24	1763	271.38
UpTanana1 – 16	408	15.98	1.45	61	4.69	39.01	1360	128.72
UpTanana2 – 17	188	9.75	1.15	20	1.31	6.97	627	23.00
UpTanana3 – 18	250	13.99	1.60	44	3.49	25.52	833	84.20
Tower1 – 19	447	28.65	2.85	198	19.77	291.41	1490	961.64
Tower2 – 20	337	37.01	3.39	199	21.23	399.73	1123	1319.10

Figure 4.4 compares stand volumes and number of trees per stand across sites. Stand volumes ranged from 2 ft^3 to 760 ft^3; average stand volume was 239 ft^3. Not surprisingly, site 9, a high-elevation site near treeline, had the lowest stand volume. Stand volume was highest at site 13, which was located on a sand dune that had a volcanic ash-loess cap.

For most sites, stand volume was much less than the number of trees in the stand. This was expected because of the small diameters of most of the trees. Stand volume was greater than tree count on only four sites; these stands also featured the four highest stand basal areas and mean total heights. Site 5 (91% black spruce); site 6 (62%), and site 8 (78%) were located in pure stands of black spruce.

Site 20 was a mixed stand comprised of 41% white spruce, 17% birch, and 9% black spruce. A few sites had plots that encompassed mixed stands. Although the first randomly located corner of the first plot encompassed a pure stand of black spruce, we observed a high degree of cover type variability within a small area. Because of the typically “patchwork” pattern of different cover types in the boreal forest, triangular or linear placement of the subsequent two plots therefore occasionally encompassed the boundary between the black spruce cover type and some other cover type such as black spruce-white spruce or black spruce-paper birch.

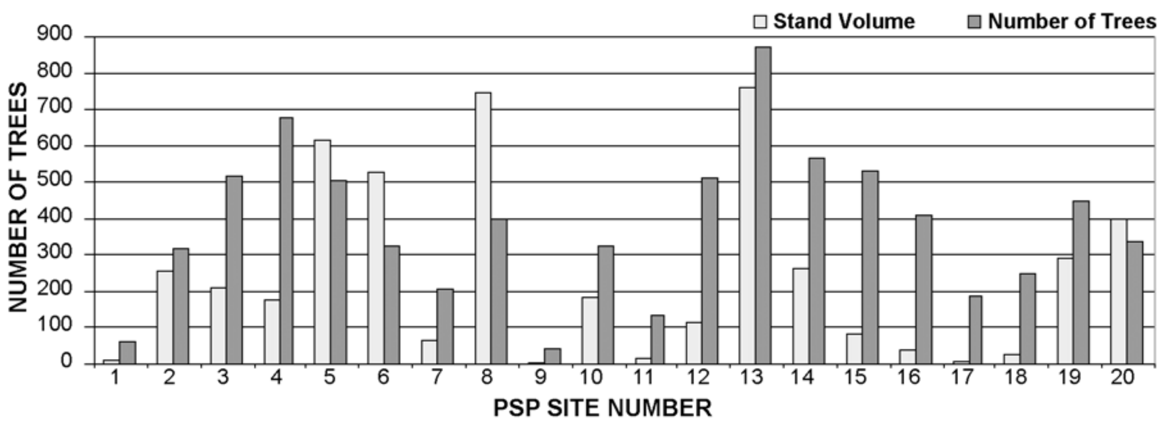

Figure 4.4. Stand volumes and number of trees per stand.

4.5 CONCLUSION

Although limited, forest inventory data from PSPs presented here and in the Appendices reveal that black spruce stands in Alaska vary widely in character; this species is not restricted to boggy low-elevation sites. As expected, landforms and soils that support pure or nearly pure stands of black spruce include lowland “muck” and organic soils. However, black spruce stands were also found on active and abandoned floodplains as well as on Aeolian, colluvial, lacustrine, and residual materials. Plot altitudes ranged from 500 to 3,500 feet; average altitude was 1,867 feet. Plots were established on level terrain (0% slope) and steep hillsides (26%) slope; average slope was 7%.

The soil was often seasonally (or permanently) frozen below organic horizons, which ranged from 2 to 15 inches in thickness. Permafrost was considered “probable” at seven sites and “unlikely” or “none” at nine sites. Ping et al. (2004) report that spruce roots are distributed mainly within the first 36 inches of the organic and upper mineral horizons, and that paralithic contact (bedrock) and permafrost, not drainage, limit rooting depth.

Plants may be restricted to sites with soil depths compatible with their rooting patterns (Oechel and Lawrence 1985); the inflexible rooting habit of black spruce helps determine its general distribution in the far north (Pulling 1918). White spruce can change rooting habit by forming a taproot on deep soils or a mat-like pedestal on soils shallow over permafrost. Black spruce, however, maintains a shallow, spreading root system and will not form a taproot even when growing in soils deep over permafrost (Oechel and Lawrence 1985). Due to an inflexible rooting habit and harsh growing conditions, black spruce is generally not a large tree in Alaska. However, we observed black spruce growing relatively better than white spruce on soils shallow over permafrost and conclude that this could be a survival strategy.

This information should aid in the study of height- and diameter-growth patterns of black spruce in Alaska north of 60° latitude, and can serve as a foundation for future forest management activity in black spruce stands.

5 Conclusions and Recommendations

This research quantifies many facets of black spruce growth in Alaska. It also partially fills a gap in the knowledge base of Alaska's boreal forests; until now, the dearth of basic growth and yield information specific to this tree species in Alaska has belied its almost ubiquitous presence throughout the Interior. We found that the average black spruce tree in this study is 83 years old and spent 26 years to reach a height of 4.5 feet. Older trees seem to grow at higher elevations. While black spruce is generally regarded as a relatively small, slow-growing tree in Alaska, it does have the capacity to be quite productive on certain site types, notably those with improved drainage conditions.

Site productivity of black spruce stands may now be estimated with new site index (height-age) curves; a new height-diameter equation also allows height to be predicted from DBH measurements. Use of height-diameter equations can be less expensive and time-consuming because only DBH measurements are needed to predict height. This will be important for forest management efforts and other studies where tight budgets are the norm. Also presented are the first estimations of individual-tree and stand volumes specifically for the sizes that black spruce commonly attains in Alaska.

Site index and volume equations presented here should be accurate for tree heights up to 50 feet, but should be used with caution when working with larger trees. Models could be expanded to accommodate larger tree sizes, but it is difficult to locate a large number of larger black spruce due to the size of the geographic region of interest and the relative lack of roads.

This research also generally describes stand-level characteristics using data obtained from the establishment of permanent sample plots. Stand-level summaries were made of diameters, heights, and densities across the Tanana Valley. Vegetation and soil characteristics were generally described as well.

I have noted several recommendations for expansion of this research:

Site index curves: Curves may be improved through the collection of more-or-less 20 sites with trees greater than 50 feet tall at 50 years of age. Curves can then be revised to better represent larger trees.

Individual-tree volume and stand volume: Additional large trees can also improve individual-tree volume estimates by collecting at least 100 more trees greater than 10 inches DBH, with particular emphasis (if possible) on trees greater than 12 inches DBH. Stand volume tables may be improved through the establishment of a large number of additional black spruce PSPs that better represent its range in Alaska and the sites — particularly those of higher quality — and community types in which it occurs.

Height-diameter ratios: Data collected for site index, individual tree volume, and PSPs can augment existing estimates of height-diameter ratios for black spruce. Opportunistic sampling of height-diameter ratios can also be made to obtain maximum values for Alaska.

Stand density index: A more comprehensive set of stand density index (SDI) values can be obtained using PSPs and temporary prism plots; the objective would be to document maximum SDI and the point where natural thinning begins.

Community types: A unified community type classification could be created by utilization of all published and unpublished sample plot data to develop a community type system for the black spruce cover type as well as for all Northern Forest cover types.

Interest in smaller trees is greater than ever before because of greater attention to tree biomass and carbon studies. I am confident that these baseline data will prove useful in further investigating the mechanisms driving black spruce productivity that are unique to this region of the boreal forest.

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7 Appendices

Appendix A. Species Codes and Plant Names.

Plant nomenclature is consistent with the online PLANTS Database (USDA-NRCS 2004).

Species	Scientific Name	Common Name
ACHBOR	*Achillea borealis* Bong.	boreal yarrow
ACODEL	*Aconitum delphiniifolium* DC.	larkspurleaf monkshood
ALNCRI	*Alnus crispa* (Ait.) Pursh	mountain alder
ALNTEN	*Alnus incana* (L.) Moench ssp. *tenuifolia* (Nutt.)	thinleaf alder
ANDPOL	*Andromeda polifolia* L.	dwarf bog-rosemary
ANEMONE sp.	*Anemone* L.	anemone
ANECAN	*Anemone canadensis* L.	Canadian anemone
ANEMUL	*Anemone multifida* Poir.	Pacific anemone
ANEPAR	*Anemone parviflora* Michx.	smallflowered anemone
ANERIC	*Anemone richardsonii* Hook.	yellow thimbleweed
ARCRUB	*Arctostaphylos rubra* (Reud & Wilson) Fern.	red fruit bearberry
ARCUVA	*Arctostaphylos uva-ursi* (L.) Spreng.	kinnikinnick
ARNANG	*Arnica angustifolia* Vahl ssp. *angustifolia*	narrowleaf arnica
ARNFRI	*Arnica frigida* C.A. Mey. ex Iljin.	snow arnica
ASTALP	*Aster alpinus* L.	alpine aster
ASTBOR	*Aster borealis* (Torr. & Gray) Prov.	northern bog aster
ASTSIB	*Aster sibiricus* L.	arctic aster
AULPAL	*Aulacomnium palustre* (Hedw.) Schwaegr.	aulacomnium moss
AULTUR	*Aulacomnium turgidum* (Wahlenb.) Schwaegr.	turgid aulacomnium moss
BETGLA	*Betula glandulosa* Michx.	shrub birch
BETNAN	*Betula nana* L.	dwarf birch
BETPAP	*Betula papyrifera* Marsh. var. *neoalaskana* (Sarg.) Raup	resin birch
BOYRIC	*Boykinia richardsonii* (Hook.) Rothrock	Richardson’s brookfoam
CALCAN	*Calamagrostis canadensis* (Michx.) Beauv.	bluejoint
CAMLAS	*Campanula lasiocarpa* Cham.	mountain harebell
CARCAN	*Carex canescens* L.	silvery sedge
CASTET	*Cassiope tetragona* (L.) D. Don	white arctic mountain heather
CETCUC	*Cetraria cucullata* (Bellardi.) Ach.	lichen
CETDEL	*Cetraria delisei* (Bory ex Schaerer) Nyl	lichen
CETISL	*Cetraria islandica* (L.) Ach.	lichen
CETNIV	*Cetraria nivalis* (L.) Ach.	lichen
CHACAL	*Chamaedaphne calyculata* (L.) Moench	leatherleaf

Species	Scientific Name	Common Name
CIRCIR	Cirriphyllum cirrosum (Schwaegr. in Schultes) Grout	cirriphyllum moss
CLADINA sp.	*Cladina* (Nyland 1996) Nyl.	reindeer lichen
CLAMIT	*Cladina mitis* (Sandst.) Hustich	reindeer lichen
CLARAN	*Cladina rangifernia* (L.) Nyl.	gray reindeer lichen
CLASTE	*Cladina stellaris* (Opiz) Brodo	star reindeer lichen
CLADONIA sp.	*Cladonia* P. Browne	cup lichen
CLABEL	*Cladonia bellidflora* (Ach.) Scher.	cup lichen
CLABOT	*Cladonia botrytes* (K. Hagen) Willd.	cup lichen
CLACAR	*Cladonia carneola* (Fr.) Fr.	cup lichen
CLACEN	*Cladonia cenotea* (Ach.) Schaer.	cup lichen
CLACER	*Cladonia cervicornis* (Ach.) Flotow ssp. *verticillata* (Hoffm.) Ahti.	cup lichen
CLACHL	*Cladonia chlorophaea* (Florke ex Somm.) Spreng.	cup lichen
CLACOC	*Cladonia coccifera* (L.) Willd.	cup lichen
CLACON	*Cladonia coniocraea* auct.	cup lichen
CLACOR	*Cladonia cornuta* (L.) Hoffm.	cup lichen
CLACRI	*Cladonia crispata* (Ach.) Flot.	cup lichen
CLADEF	*Cladonia deformis* (L.) Hoffm.	deformed cup lichen
CLAECM	*Cladonia ecomycna* Leight.	cup lichen
CLAGRA	*Cladonia gracilis* (L.) Willd.	cup lichen
CLAMUL	*Cladonia multiformis* G. Merr.	cup lichen
CLAPOR	*Cladonia pocillum* (Ach.) Grognot	cup lichen
CLASQU	*Cladonia squamosa* Hoffm.	cup lichen
CLAUNC	*Cladonia uncialis* (L.) F.H. Wigg.	cup lichen
CLIDEN	*Climacium dendroides* (Hedw.) Web. & Mohr.	tree climacium moss
CORCAN	*Cornus canadensis* L.	bunchberry dogwood
DACARI	*Dactylorhiza aristata* (Fisch. ex Lindl.) Soó	keyflower
DELGLA	*Delphinium glaucum* S. Wats.	Sierra larkspur
DICRANUM sp.	*Dicranum* Hedw.	dicranum moss
DICSCO	*Dicranum scoparium* Hedw.	dicranum moss
DREPAN sp.	*Drepanocladus* (C. Müll.) G. Roth	drepanocladus moss
DROROT	*Drosera rotundifolia* L.	roundleaf sundew
DRYINT	*Dryas integrifolia* Vahl	entireleaf mountain-avens
ELYGLA	*Elymus glaucus* Buckl.	blue wildrye
EMPNIG	*Empetrum nigrum* L.	black crowberry
EPIANG	*Epilobium angustifolium* L.	fireweed
EQUARV	*Equisetum arvense* L.	field horsetail

Species	Scientific Name	Common Name
EQUPRA	*Equisetum pratense* Erh.	meadow horsetail
EQUSCI	*Equisetum scirpoides* Michx.	dwarf scouringrush
EQUSYL	*Equisetum sylvaticum* L.	woodland horsetail
ERIANG	*Eriophorum angustifolium* Honck.	tall cottongrass
GALBOR	*Galium boreale* L.	northern bedstraw
GALTRI	*Galium trifidum L.*	threepetal bedstraw
GENPRO	*Gentiana prostrata* Haenke	pygmy gentian
GEOLIV	*Geocaulon lividum* (Richards) Fern.	false toadflax
GERERI	*Geranium erianthum* DC.	woolly geranium
GOOREP	*Goodyera repens* (L.) R. Br. Ex Ait. f.	lesser rattlesnake plantain
HEDALP	*Hedysarum alpinum* L.	alpine sweetvetch
HEDCIL	*Hedwigia ciliata* (Hedw.) P. Beauv.	ciliate hedwigia moss
HYLSPL	*Hylocomium splendens* (Hedw.) B.S.G.	splendid feathermoss
HYPNUM sp.	*Hypnum* sp.	hypnum moss
HYPLIN	*Hypnum lindbergii* Mitt.	hypnum moss
HYPSUB	*Hypnum subimponens* Lesq.	hypnum moss
JUNCOM	*Juniperus communis* L.	common juniper
JUNHOR	*Juniperus horizontalis* Moench	creeping juniper
LARLAR	*Larix laricina* (DuRoi) K. Koch	tamarack
LEDUM sp.	*Ledum* L.	Labrador tea
LEDGRO*	*Ledum groenlandicum* Oeder	bog Labrador tea
LEDPAL*	*Ledum palustre* L. spp. *decumbens* (Ait.) Hultén	marsh Labrador tea
**Ledum* species are not differentiated in the relevés and are counted together as *Ledum* sp.		
LINBOR	*Linnaea borealis* L.	twinflower
LOPHOZIA sp.	*Lophozia* (Dumort.) Dumort.	liverwort
LOPVEN	*Lophozia ventricosa* (Dicks.) Dum.	liverwort
LUPARC	*Lupinus arcticus* S. Wats	arctic lupine
LYCANN	*Lycopodium annotinum* L.	stiff clubmoss
LYCCLA	*Lycopodium clavatum* L.	running clubmoss
LYCCOM	*Lycopodium complanatum* L.	groundcedar
MEESIA sp.	*Meesia* Hedw.	meesia moss
MENFER	*Menziesia ferruginea* Sm.	rusty menziesia
MERPAN	*Mertensia paniculata* (Ait.) G. Don	tall bluebells

Species	**Scientific Name**	**Common Name**
MOELAT	*Moehringia laterifolia* (L.) Fenzl	bluntleaf sandwort
NEPARC	*Nephroma arcticum* L. Torss.	arctic kidney lichen
NEPEXP	*Nephroma expallidum* (Nyl.) Nyl.	kidney lichen
ORTSEC	*Orthilia secunda* (L.) House	sidebells wintergreen
PARPAL	*Parnassia palustris* L.	marsh grass of Parnassus
PEDCAP	*Pedicularis capitata* M.F. Adams	capitate lousewort
PEDLAB	*Pedicularis labradorica* Wirsing	Labrador lousewort
PELTIGERA sp.	*Peltigera* Willd.	felt lichen
PELAPH	*Peltigera aphthosa* (L.) Willd.	felt lichen
PELCAN	*Peltigera canina* (L.) Willd.	felt lichen
PELMAL	*Peltigera malacea* (Ach.) Funck	felt lichen
PELNEO	*Peltigera neopolydactyla* (Gyelnik) Gyelnik	felt lichen
PETFRI	*Petasites frigidus* (L.) Franch.	Arctic sweet coltsfoot
PETSAG	*Petasites sagittatus* (Banks) Gray	sweet coltsfoot
PICGLA	*Picea glauca* (Moench) Voss	white spruce
PICMAR	*Picea mariana* (Mill.) B.S.P.	black spruce
PLAOBT	*Platanthera obtusata* (Banks ex Pursh) Lindl.	bluntleaved orchid
PLESCH	*Pleurozium schreberi* (Brid.) Mitt.	Schreber's big red stem moss
POAGLA	*Poa glauca* Vahl	glaucous bluegrass
POAPAL	*Poa palustris* L.	fowl bluegrass
POLACU	*Polemonium acutiflorum* Willd. ex Roemer & J.A. Schultes	tall Jacob's-ladder
POLALA	*Polygonum alaskanum* W. Wight ex Hultén	Alaska wild rhubarb
POLCOM	*Polytrichum commune* Hedw.	polytrichum moss
POLJUN	*Polytrichum jumiperinum* Hedw.	polytrichum moss
POLPIL	*Polytrichum pilferum* Hedw.	polytrichum moss
POPBAL	*Populus balsamifera* L.	balsam poplar
POPTRE	*Populous tremuloides* Michx.	quaking aspen
POTFRU	*Potentilla fruticosa* auct. non L.	shrubby cinquefoil
PTICRI	*Ptilium crista-castrensis* (Hedw.) De Not.	knights plume moss
PYRCHL	*Pyrola chlorantha* Sw.	green-flowered wintergreen
PYRGRA	*Pyrola grandiflora* Radius	large-flowered wintergreen
RIBGLA	*Ribes glandulosum* Grauer	skunk currant
RIBHUD	*Ribes husdonsianum* Richards.	northern black currant
RIBLAC	*Ribes lacustre* (Pers.) Poir.	prickly currant

Species	Scientific Name	Common Name
RIBTRI	*Ribes triste* Pallas	red currant
ROSACI	*Rosa acicularis* Lindl.	wild rose
RUBUS sp.	*Rubus* L.	blackberry
RUBARC	*Rubus arcticus* L. ssp. *acaulis* (Michx.) Focke.	dwarf raspberry
RUBCHA	*Rubus chamaemorus* L.	cloudberry
RUBIDA	*Rubus idaeus* L.	American red raspberry
RUBPED	*Rubus pedatus* Sm.	strawberryleaf raspberry
RUMARC	*Rumex arcticus* Trautv.	arctic dock
SALIX sp.	*Salix* L.	willow
SALALA	*Salix alaxensis* (Anderss.) Coville	feltleaf willow
SALRET	*Salix reticulata* L.	netted willow
SANCAN	*Sanguisorba canadensis* L.	Canadian burnet
SAUANG	*Saussurea angustifolia* (Willd.) DC.	narrowleaf saw-wort
SAXIFRAGA sp.	*Saxifraga* L.	saxifrage
SENECIO sp.	*Senecio* L.	ragwort
SHECAN	*Shepherdia canadensis* (L.) Nutt.	russet buffaloberry
SOLDEC	*Solidago decumbens* Greene var. *oreophila* (Rydb.) Fern.	dwarf goldenrod
SPHANG	*Sphagnum angustifolium* (C. Jens. ex Russ.) C. Jens. in Tolf	sphagnum moss
SPHCAP	*Sphagnum capillifolium* (Ehrh.) Hedw.	sphagnum moss
SPHFUS	*Sphagnum fuscum* (Schimp.) Klinggr.	sphagnum moss
SPHGIR	*Sphagnum girgensohnii* Russ.	Girgensohn's sphagnum
SPHMAG	*Sphagnum magellanicum* Brid.	Magellan's sphagnum
SPHSQU	*Sphagnum squarrosum* Crome	sphagnum moss
SPIBEA	*Spiraea beauverdiana* auct. non Schneid.	beauverd spiraea
SPIROM	*Spiranthes romanzoffiana* Cham. var. *diluvialis* (Sheviak) Welsh.	diluvim ladies'-tresses
STELON	*Stellaria longipes* Goldie	longstalk starwort
THUABI	*Thuidium abietinum* (Hedw.) Schimp. in B.S.G.	abietinella moss
TOMENT sp.	*Tomenthypnum* Loeske	tomenthypnum moss
TRIEUR	*Trientalis europaea* L. var. *latifolia* (Hook.) Torr.	broadleaf starflower
VACULI	*Vaccinium uliginosum* L.	bog blueberry
VACVIT	*Vaccinium vitis-idaea* L.	lingonberry
VALCAP	*Valeriana capitata* Pallas ex Link ssp. *acutiloba* (Rydb.) F.G. Mey.	sharpleaf valerian
VIBEDU	*Viburnum edule* (Michx.) Raf.	squashberry
VIOEPI	*Viola epipsila* Ledeb.	dwarf marsh violet
VIOPAL	Viola palustris L.	marsh violet

Appendix B. Tree Species Scientific and Common Names.

Plant nomenclature is consistent with the online PLANTS Database (USDA-NRCS 2004).

Scientific Name	Common Name
Abies alba Mill.	white fir
Abies balsamea (L.) P. Mill.	balsam fir
Abies lasiocarpa (Hook.) Nutt. var. *lasiocarpa*	subalpine fir
Acer pensylvanicum L.	striped maple
Acer rubrum L.	red maple
Acer saccharum Marsh.	sugar maple
Aesculus flava Ait.	yellow buckeye
Alnus incana (L.) Moench ssp. *rugosa* (Du Roi) Clausen	speckled alder
Betula alleghaniensis Britt.	yellow birch
Betula neoalaskana L.	paper birch
Betula populifolia Marsh.	gray birch
Chamaecyparis thyoides (L.) B.S.P.	northern white-cedar
Fagus grandifolia Ehrh.	American beech
Fraxinus nigra Marsh.	black ash
Larix laricina (Du Roi) K. Koch	tamarack
Ostrya virginiana (Mill.) K. Koch	eastern hophornbeam
Picea engelmanii Parry ex. Engelm.	Engelmann spruce
Picea glauca (Moench) Voss.	white spruce
Picea rubens Sarg.	red spruce
Picea mariana (Mill.) B.S.P.	black spruce
Pinus contorta Dougl. ex Loud.	lodgepole pine
Pinus ponderosa P. & C. Lawson	ponderosa pine
Pinus resinosa Soland.	red pine
Pinus strobus L.	eastern white pine
Populus balsamifera L. ssp. balsamifera	balsam poplar
Populus grandidentata Michx.	bigtooth aspen
Populus tremuloides Michx.	quaking aspen
Quercus macrocarpa Michx.	bur oak
Quercus palustris Muenchh.	northern pin oak
Quercus rubra L.	red oak
Quercus rubra L. var. *rubra*	northern red oak
Prunus pensylvanica L. f.	pin cherry
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Sorbus L.	mountain ash
Tsuga canadensis (L.) Carr.	eastern hemlock

Appendix C. PSP Sites: Physiographic Features.

SITES 1-10 Locations	Birch1 RichHwy 308.8N	Birch2 RichHwy 301.3N	Tok1 Tok Cutoff 112.8N	Smith1 UAF Arboretum	Smith2 UAF Arboretum	Himal Hiimalaya Rd 3.2N	Cleary Fish Creek Rd 4W	9Mile Taylor Hwy 9S	Fair1 Taylor Hwy 34S	14Mile Taylor Hwy 14S
Established	16-Jun-01	16-Jun-01	20-Jun-01	25-May-02	2-Jun-02	14-Jun-02	20-Jun-02	28-Jun-02	1-Jul-02	2-Jul-02
Altitude, ft	880	1070	1780	500	550	1400	2000	2600	3500	2900
Aspect, deg	3.6	90	360	180	190	360	29	155	360	315
Slope, %	none	4	none	2	4	16	18	11	26	3
1 Permafrost	1	5	2	1	1	2	3	3	3	3
2 Slope position	6	6	8	8	4	2	2	2	2	1
3 Contour	2	4	2	2	2	1	2	3	4	2
4 Bedrock	3	3	3	3	4	2	3	2	2	3
5 Landform	6	6	4	3	1	11	2	11	11	8
6 Texture	N/A	N/A	4	N/A	6	4	4	N/A	5	5
Organic, in	8	15	6	4	4	14	12	8	7	6
Mineral, in	none	none	8	none	none	none	6	12	3	11
7 Soil moisture	N/A	N/A	3	N/A	4	3	4	3	4	1
Exp min soil, %	none	none	none	none	none	none	0.5	none	none	none
Litter, % cover	0.5	1	1	1	0.5	1	0.5	none	1	2
D/D wood, %*	0.5	0.5	2	1	2	1	none	2	1	2
Standing snags	28	17	10	12	120	15	none	15	none	24
SITES 11-20 Locations	Fair2 Taylor Nwy 32N	Tok2 Tok Cutoff 108.5E	Dune AK Hwy 1298N	Smith3 UAF Arboretum	Cathed AK Hwy 1434E	UpTan1 AK Hwy 1243.8S	UpTan2 AK Hwy 1235.5S	UpTan3 AK Hwy 1230N	Tower1 AK Hwy 1267.3N	Tower2 AK Hwy 1267.3N
Established	12-Jul-02	14-Jul-02	17-Jul-02	25-Jul-02	30-Jul-02	09-Aug-02	10-Aug-02	10-Aug-02	23-Aug-02	24-Aug-02
Altitude, ft	3250	2000	1900	520	1550	2000	2100	1900	2500	2450
Aspect, deg	282	120	350	10	332	190	150	82	62	214
Slope, %	12	2	8	1	6	6	1	6	5	3
1 Permafrost	3	3	4	2	2	2	2	2	3	4
2 Slope position	none	5	2	6	8	4	6	4	1	1
3 Contour	2	2	2	2	2	4	2	2	1	2
4 Bedrock	3	3	3	4	2	4	4	4	2	2
5 Landform	10	8	2	8	4	6	2	8	none	2
6 Texture	3	2	2	6	4	5	2	2	N/A	4
Organic, in	7	7	6	6	10	10	8	7	8	2
Mineral, in	1	none	20+	7	25	2	12	4	2	12
7 Soil moisture	4	3	5	6	3	3	3	1	N/A	6
Exp min soil, %	none	none	none	none	none	none	none	none	none	none
Litter, % cover	none	1	none	1	none	1	none	none	none	2
D/D wood, %*	1	4	2	3	3	2	1	1	1	2
Standing snags	4	24	17	19	24	14	none	3	6	7

Dead and downed wood CODE DESCRIPTORS:

1 Likelihood of permafrost: near surface–1; probable–2; unlikely–3; none–4; unknown–5
2 Slope position: crest–1; upper–2; middle–3; lower–4; toe–5; stream bottom–6; bench/flat–7; depression–8
3 Land contour: convex–1; straight–2; concave–3; undulating–4
4 Bedrock type: igneous–1; metamorphic–2; sedimentary–3; none–4
5 Landform type: colluvial–1; Aeolian–2; floodplain (active)–3; floodplain (abandoned)–4; floodplain (other)–5; lowland “muck”–6; glacial–7; lacustrine–8; marine–9; organic–10; residual–11; manmade–12
6 Soil texture: gravel–1; sand–2; loam–3; silt–4; clay–5; organic–6
7 Soil moisture: peraquic–1; aquic–2; subaquic–3; perhumid–4; humid–5; subhumid–6; subxeric–7; xeric–8

Appendix D. PSP Sites: Vascular Plants.

SITES 1–10	Birch1	Birch2	Tok1	Smith1	Smith2	Himal	Cleary	9Mile	Fair1	14Mile
TREES (>4.5')										
LARLAR	T					T		T	T	
PICGLA			5-25							
PICMAR	1–5	50-75	25–50		5-25		T	T		
BETPAP					25–50	5-25	5-25	50-75	1–5	25–50
REGENERATION (<4.5')										
LARLAR	1–5									
PICGLA			5-25							
PICMAR	25–50	5-25	5-25		5-25					
BETPAP	T			1–5	1–5	1–5	1–5	5-25	1–5	1–5
SHRUBS										
ALNCRI								1–5	5-25	
ALNTEN						T		T	5-25	
ARCRUB							T		5-25	
ARCUVA	1–5			25–50	25–50					
BETGLA	1–5			T			50-75		25–50	1–5
BETNAN	5-25	1–5		1–5			50-75		50-75	5-25
CASTET									T	
EMPNIG		1–5	1–5	1–5	25–50		1–5	T	1–5	
LEDUM sp.	1–5	5-25	1–5	1–5	25–50	T	1–5	25–50	5-25	
POTFRU			T	T						25–50
RIBHUD		1–5						T		
ROSACI			1–5	T	T	25–50				
RUBUS sp.		1–5								1–5
RUBARC					T		T			
RUBCHA	1–5			1-5		T				
SALIX sp.	1–5	25–50	1–5	1–5	1–5		1–5		5-25	
SPIBEA						1–5	T			
VACULI	1–5	5-25	T	1–5	1–5	T	1–5		5-25	1–5
VACVIT	1–5	5-25	1–5	1–5	1–5	25–50	1–5	50-75	5-25	25–50
VIBEDU					T					1–5
GRASSES										
CALCAN				1–5	1–5	1–5				
CARCAN		1–5								1–5
POAGLA									50-75	
POAPAL										T
unknown	50-75				1–5			5-25	25–50	
SEDGES										
ERIANG				1-5			1–5			
ERICHA				1-5						1–5
HERBS										
ARNANG					1-5					
ARNFRI				1-5						
CORCAN		T	T		T	T				
DACARI									T	
EPIANG					T					
EQUARV					1–5	T				
EQUSCI				T						
EQUSYL						5-25				
GEOLIV					T			25–50		
MERPAN			T		T			T		
MOELAT					1-5					
ORTSEC				1-5						
PETFRI		1–5			T				1–5	T
PYRCHL				T						
SAXIFRAGA sp.									T	
Cover classes are by percent. “T” signifies a percent cover of 0.5 and represents instances of a single or few individuals.										

SITES 11–20	Fair2	Tok2	Dune	Smith3	Cathed	UpTan1	UpTan2	UpTan3	Tower1	Tower2
TREES (>4.5')										
LARLAR				T		1-5	1-5		1–5	1–5
PICGLA							1–5			
PICMAR	25–50	T	5-25	1–5	25-50				5-25	25–50
BETPAP	1–5	25–50	25–50	25–50	1–5	25–50	1–5	25–50	25–50	5-25
REGENERATION (<4.5')										
LARLAR				1–5						
PICGLA							5-25			1–5
PICMAR	1–5		25–50	1–5	25–50				1–5	1–5
BETPAP	1–5	50-75	25–50	25–50	25–50	25–50	1–5	25–50	2.5	1–5
SHRUBS										
ALNCRI	1–5					1–5			25–50	1–5
ALNTEN	T									
ARCRUB		50-75		1–5	T	25–50	1–5	25–50		
ARCUVA										
BETGLA	25–50			1–5			T	T		
BETNAN	5-25			25–50	25–50		1–5	T		
CHACAL					T	T	1–5			
EMPNIG	50-75	25–50	1–5	1–5	T		T	1–5		
LEDUM sp.	1–5	25–50	1–5	1–5	50-75	5-25	25–50	1–5	75-95	50-75
POTFRU						1–5	1–5	T		
ROSACI		1–5		T					1-5	1–5
RUBCHA	T	25–50		5-25		1–5	1–5	25–50		
SALIX sp.	T	1–5	T	25–50	1–5	1–5	5-25	1–5	25–50	25–50
VACULI	50-75	1–5		1–5	25–50	1–5	1–5	1–5	1–5	
VACVIT	25–50	50-75	1–5	50-75	1–5	25–50	1–5	T	50-75	50-75
GRASSES										
CALCAN	1–5	50-75		1–5		1–5				
CARCAN		1–5								
POAPAL					1–5					
unknown	1–5		1–5	50-75	1–5		1–5	1–5		50-75
SEDGES										
ERIANG	1–5	1–5		T	1–5	25–50	75-95	1–5		
HERBS										
ANDPOL							T	1–5		
CORCAN		1–5		T						
DELGLA						1–5				
DROROT						1–5				
EQUARV					T					
EQUPRA					T					T
EQUSCI					T	1–5	T	1–5		
EQUSYL						T				
GEOLIV		1–5	25–50	1–5		T			1–5	1–5
LINBOR			T							T
MERPAN			T							T
PARPAL								T		
PETFRI		5-25		5-25				T		
PYRCHL		T		T						1-5
PYRGRA									1-5	
SAUANG							T	T		
SPIROM								T		

Cover classes are by percent. “T” signifies a percent cover of 0.5 and represents instances of a single or few individuals.

Appendix E. PSP Sites: Non-Vascular Plants.

SITES 1–10	Birch1	Birch2	Tok1	Smith1	Smith2	Himal	Cleary	9Mile	Fair1	14Mile
LICHENS										
CETCUC					T		T	1–5	1–5	25–50
CETISL										T
CLAMIT	T		5-25		T		1–5	1–5	T	5-25
CLARAN					1-5		1–5	1–5	1–5	1–5
CLASTE							1–5			
CLADONIA sp.				T		T			T	
CLABEL										T
CLACEN										T
CLACER								T		
CLACOR										1–5
CLACRI								1–5	1–5	T
CLADEF								T		1–5
CLAECM								T		1–5
CLAGRA										T
CLAPOR								T		
CLAUNC					1-5					
NEPARC							5-25			1–5
NEPEXP					1–5					
PELTIGERA sp.				1-5		T				
PELAPH	1–5				1-5	T	T	1–5	T	1–5
PELCAN								1–5		
PELMAL										T
STEPAS							1–5			
MOSSES										
AULPAL					1–5					1–5
AULTUR					1–5					
CIRCIR									1–5	
CLIDEN										1–5
HEDCIL									T	1–5
HYLSPL			25–50	1–5		50-75			25–50	25–50
HYPNUM sp.								1–5		
LYCCLA									1–5	
LYCANN					1–5		T			
LYCCOM							T			
PLESCH	5-25		25–50	1–5		50-75				1–5
POLCOM						1–5			T	1–5
POLJUN					1-5					
POLPIL								25–50	T	
PTICRI						1–5		1–5	1–5	
RHYRUG									T	
SPHAGNUM sp.				T						
SPHANG						5-25			T	T
SPHGIR						1–5				
THUABI					50-75	1–5	25–50	1-5	1–5	1–5
Cover classes are by percent. “T” signifies a percent cover of 0.5 and represents instances of a single or few individuals.										

SITES 11–20	Fair2	Tok2	Dune	Smith3	Cathed	UpTan1	UpTan2	UpTan3	Tower1	Tower2
LICHENS										
CETCUC	1–5				T					
CETISL					T			T		
CLADINA sp.			T					T	T	1-5
CLAMIT		1–5	T	1–5	50-75	1–5	1–5	5-25	1-5	1-5
CLARAN	1–5			1–5	25–50	T	1–5	5-25	1-5	1-5
CLASTE					1–5			0.1–5		
CLABOT					T					
CLACER								1-5		
CLACOC								T		
CLACOR		T								
CLAGRA		1–5			T			T	1-5	1-5
NEPARC			T							
NEPEXP				1–5						
PELTIGERA sp.			1–5							
PELAPH		T	5-25	1–5			1–5	T	1–5	1–5
PELNEO			5-25						T	1–5
MOSSES										
AULPAL					1–5	25–50	25–50	25–50		
AULTUR	1–5	5-25			T		T			
DICRANUM sp.		1–5					T		T	
DICSCO							T			
HEDCIL				T						
HYLSPL	1–5	25–50	50-75	50-75	T	T	5-25	25–50	75-95	25–50
HYPNUM sp.			1–5							
HYPSUB			1–5							
LYCANN						T			T	1–5
PLESCH	1–5		1–5	1–5	25–50	1–5	1–5			
POLCOM	1–5		T		T				1–5	1–5
POLJUN					T					
PTICRI			25–50						1–5	
SPHAGNUM sp.							1–5			
SPHANG	1–5	1–5		T						
SPHCAP					1–5	1–5	1–5			
SPHFUS	1–5	1–5		T	T	1–5	1–5			
SPHGIR	5-25	1–5		1–5						
SPHMAG		1–5		T						
SPHSQU				1–5						
THUABI	1–5	25–50	50-75		T		1–5	50-75	T	1–5
TOMENTHYPNUM sp.							1–5			
LIVERWORTS										
LOPHOZIA sp.						1–5				
LOPVEN							T			
Cover classes are by percent. “T” signifies a percent cover of 0.5 and represents instances of a single or few individuals.										

Appendix F. Stem Analysis Sites: Physiographic Features.

SITES 1–10 Locations	LShot 1 FAI, Little Shot Trail	GoldH 2 Parks Hwy Goldhill Rd	Lasher 3 Tanana R Quist Fm	Tanana 4 AK Hwy 1303N	Zasad1 5 Parks Hwy 340E	Zasad2 6 Parks Hwy 340E	Bluff 7 Rich Hwy 294S	ShawC 8 Rich Hwy 285.2N	Tok3 9 Tok Cutoff 111.2S	DotLk 10 AK Hwy 1373.2
Established	25-May-01	31-May-01	3-Jun-01	24-Au-01	1-Jun-01	15-Jun-01	17-Jun-01	17-Jun-01	19-Jun-01	20-Jun-01
Altitude, ft	450	450	400	1800	1400	1400	1000	1000	1800	1600
Aspect, deg	154	190	180	322	324	8	278	152	0	180
Slope, %	2	4	1	4	3	12	2	1		5
1 Permafrost	2	3	2	3	3	3	2	2	1	2
2 Slope position	3	4	7	7	2	2	7	8	8	5
3 Contour	4	3	2	4	1	1	2	2	2	3
4 Bedrock	3	4	4	4	4	4	3	3	4	none
5 Landform	2	2	4	4	2	2	4	4	10	4
6 Texture	4	4	6	4	4	4	6	4	4	1
Organic, in	6	5.5	9	7	7	7.5	6.5	6	5	6
Mineral, in	4	5	2	23	3	4.5	none	none	5	9.5
Volcanic ash, in	none	none	none	none	none	none	none	0.25	none	none
7 Soil moisture	5	3	3	2	5	4	none	none	2	1
Exp min soil, %	1	1	1	1	1	none	1	1	1	5
Litter, % cover	none	none	none	1	none	none	none	none	none	none
D/D wood, %*	1	1	1	2	2	1	2	1	1	none
SITES 11–20 Locations	Reeve1 11 Fox, Goldstr Rd	Reeve2 12 Fox, Goldstr Rd	PedroD 13 Pedro Dome	DelSch 14 School at Delta Jct	EddyDZ 15 Fort Greeley	12MileT 16 Taylor Hwy 12S	FaiCk 17 Fbks Ck Rd 3S	Tok4 18 Tok cutoff 105N	Tok5 19 Tok cutoff 107N	Tok6 20 Tok cutoff 110N
Established	2-Jul-01	3-Jul-01	16-Jul-01	22-Au-01	9-Au-01	30-Jun-02	13-My-02	13-Jul-02	15-Jul-02	29-Jul-02
Altitude, ft	650	600	2000	1200	1200	2800	1600	1800	1800	1800
Aspect, deg	348	340	360	274	360	74	130	0	26	150
Slope, %	5	15	32	1	1	4	20	none	4	1
1 Permafrost	2	2	3	3	3	3	3	2	3	3
2 Slope position	3	4	2	7	8	2	3	7	7	7
3 Contour	4	3	3	2	2	3	2	2	2	2
4 Bedrock	4	4	2	4	3	3	2	3	3	3
5 Landform	4	1	11	4	4	8	2	4	4	4
6 Texture	4	4	6	4	3	5	4	4	2	2
Organic, in	8.5	13	6	6	3	6	2	6	7	3
Mineral, in	3	3	2	24	32	21	6	4	8	7
Volcanic ash, in	none	none	none	1	none	none	none	none	none	none
7 Soil moisture	5	3	4	5	5	2	3	3	3	7
Exp min soil, %	none	1	none	1	none	1	2	1	none	1
Litter, % cover	none	none	none	none	none	none	none	none	none	none
D/D wood, %*	1	1	none	1	none	1	1	1	2	2

**Dead and downed wood*

CODE DESCRIPTORS:

1 **Likelihood of permafrost:** near surface–1; probable–2; unlikely–3; none–4; unknown–5

2 **Slope position:** crest–1; upper–2; middle–3; lower–4; toe–5; stream bottom–6; bench/flat–7; depression–8

3 **Land contour:** convex–1; straight–2; concave–3; undulating–4

4 **Bedrock type:** igneous–1; metamorphic–2; sedimentary–3; none–4

5 **Landform type:** colluvial–1; Aeolian–2; floodplain (active)–3; floodplain (abandoned)–4; floodplain (other)–5; lowland “muck”–6; glacial–7; lacustrine–8; marine–9; organic–10; residual–11; manmade–12

6 **Soil texture:** gravel–1; sand–2; loam–3; silt–4; clay–5; organic–6

7 **Soil moisture:** peraquic–1; aquic–2; subaquic–3; perhumid–4; humid–5; subhumid–6; subxeric–7; xeric–8

SITES 21-30 Locations	7Mile 21 Taylor Hwy 7S	Gerstle 22 AK Hwy at Gerstle Rv	Stand1 23 Standard Ck Rd	Nenana 24 Parks Hwy at Nenana	Elliott 25 Elliott Hwy 86.4	OldMil 26 Parks Hwy 331.5	Pardse1 27 AK Hwy 1240	Stand2 28 Stand Ck Rd 4.9S	Kenai1 29 Sterling Hwy 109.6	Kenai2 30 Sterling Hwy 121.7
Established	11-Aug-02	1-Aug-02	11-Aug-88	10-Oct-88	16-Jun-89	5-Aug-89	11-Aug-89	14-Jun-95	22-Jun-95	22-Jun-95
Altitude, ft	2200	1400	600	500	800	1000	2250	800	100	250
Aspect, deg	30	none	none	none	50	140	160	130	none	162
Slope, %	8	none	none	none	25	5	5	11	none	58
1 Permafrost	3	3	4	1	4	2	3	2	1	1
2 Slope position	3	8	8	8	3	3	2	2	8	3
3 Contour	4	2	3	2	2	2	2	2	2	2
4 Bedrock	3	3	4	4	4	4	4	2	3	3
5 Landform	11	4	4	4	11	2	7	2	6	6
6 Texture	2	3	4	4	3	3	3	4	4	3
Organic, in	8	5	1	4	6	2	1	9	9	10
Mineral, in	20	11	36	36	none	none	none	none	none	none
Volcanic ash, in	0.50	none	none	none	none	none	none	none	none	none
7 Soil moisture	6	7	6	5	5	4	4	7	4	4
Exp min soil, %	none	none	2	2	5	2	4	1	none	1
Litter, % cover	none	none	none	none	none	none	none	none	none	none
D/D wood, %*	none	none	none	none	none	none	none	none	none	none
SITES 31-40 Locations	Kenai3 31 Swanson R Rd 9.3	Kenai4 32 Swan Lake Rd 2.0	Kenai5 33 Swanson R Rd 19.4	Kenai6 34 Swanson R Rd 17.6	Kenai7 35 Snug Hbr Rd 0.1	Pardse2 36 AK Hwy 1238	Montana 37 L. Davie, Talkeetna	Willow 38 Parks Hwy 76, Willow	Tyonek1 39 Pt Macken Rd 1.4	Tyonek2 40 Burma Rd 1.7
Established	23-Jun-95	23-Jun-96	23-Jun-95	23-Jun-95	24-Jun-95	23-Jul-95	24-Aug-96	24-Aug-96	25-Aug-96	25-Aug-96
Altitude, ft	200	200	200	200	1000	2700	400	150	100	175
Aspect, deg	360	320	332	340	220	none	none	none	62	350
Slope, %	8	3	10	14	20	none	none	none	4	14
1 Permafrost	3	3	4	3	2	3	3	4	3	3
2 Slope position	8	8	1	3	4	3	6	8	6	4
3 Contour	1	2	1	2	2	4	4	2	4	4
4 Bedrock	3	3	3	3	3	2	2	2	2	2
5 Landform	2	7	7	2	7	11	6	none	none	none
6 Texture	3	3	3	3	5	4	4	3	3	3
Organic, in	5	5	1	2	5	3	6	6	5	6
Mineral, in	none	none	none	none	none	2	none	21	none	none
Volcanic ash, in	none	none	1	none	none	none	none	none	none	1
7 Soil moisture	5	3	5	5	5	5	3	3	3	3
Exp min soil, %	none	none	none	none	none	1	1	1	1	1
Litter, % cover	none	none	none	none	none	none	none	none	none	none
D/D wood, %*	none	none	none	none	none	none	none	none	none	none

**Dead and downed wood .*

CODE DESCRIPTORS:

1 Likelihood of permafrost: near surface–1; probable–2; unlikely–3; none–4; unknown–5
2 Slope position: crest–1; upper–2; middle–3; lower–4; toe–5; stream bottom–6; bench/flat–7; depression–8
3 Land contour: convex–1; straight–2; concave–3; undulating–4
4 Bedrock type: igneous–1; metamorphic–2; sedimentary–3; none–4
5 Landform type: colluvial–1; Aeolian–2; floodplain (active)–3; floodplain (abandoned)–4; floodplain (other)–5; lowland “muck”–6; glacial–7; lacustrine–8; marine–9; organic–10; residual–11; manmade–12
6 Soil texture: gravel–1; sand–2; loam–3; silt–4; clay–5; organic–6
7 Soil moisture: peraquic–1; aquic–2; subaquic–3; perhumid–4; humid–5; subhumid–6; subxeric–7; xeric–8

SITES 41-50 Locations	Petersv 41 Petersville Rd 5.7	DelFarm 42 AK Hwy 1408	FaiFarm 43 UAF Exp. Farm	Dalton1 44 Coldfoot, Marion Ck	Dalton2 45 Dalton 146.2E	Dalton3 46 Dalton 92.8W	Dalton4 47 Dalton 78.2 E	Dalton5 48 Dalton 63.2E	Dalton6 49 Dalton 49.6E	Dalton7 50 Dalton 37.3E
Established	23-Aug-96	28-Aug-00	2-Jun-03	11-Jun-03	11-Jun-03	6/1099	11-Jun-03	11-Jun-03	11-Jun-03	12-Jun-03
Altitude, ft	500	1200	480	2000	1175	1775	700	650	1400	900
Aspect, deg	none	150	none	none	262	14	none	188	305	none
Slope, %	none	2	none	none	5	7	none	3	3	none
1 Permafrost	3	5	1	2	1	1	1	1	1	1
2 Slope position	6	7	8	8	4	3	3	8	2	3
3 Contour	4	2	2	2	2	2	2	2	2	2
4 Bedrock	2	3	4	4	4	4	4	4	4	4
5 Landform	none	none	10	4	6	10	10	10	10	2
6 Texture	none	3	6	4	6	6	6	6	6	4
Organic, in	12	5	8	3	5	6	1	7	3	3
Mineral, in	14	25	none	3	none	none	none	none	none	2
Volcanic ash, in	none	none	none	none	none	none	none	none	none	none
7 Soil moisture	2	6	none	6	4	4	4	6	6	6
Exp min soil, %	1	1	2	1	1	1	1	1	none	2
Litter, % cover	1	none	none	none	none	none	none	none	none	none
D/D wood, %*	none	none	1	1	none	none	1	1	none	1
SITES 51-60 Locations	Dalton8 51 Dalton 11.3W	Chatan 52 Chat Lodge	Taylor1 53 Taylor Hwy 124.1W	Taylor2 54 Taylor Hwy 122.2W	Taylor3 55 Taylor Hwy 62.0	Taylor4 56 Taylor Hwy 61.0	Taylor5 57 Taylor Hwy 59.9	Taylor6 58 Taylor Hwy 40.9W	Taylor7 59 Taylor Hwy 20.6W	Taylor8 60 Taylor Hwy 19.0
Established	12-Jun-03	15-Apr-05	27-Jul-97	27-Jul-97	28-Jul-97	28-Jul-97	28-Jul-97	29-Jul-97	29-Jul-97	29-Jul-97
Altitude, ft	1400	700	1650	2150	2150	2290	2200	2500	3060	2650
Aspect, deg	315	340	128	118	70	188	145	50	266	214
Slope, %	16	1	16	26	4	3	24	13	10	2
1 Permafrost	1	2	3	3	2	2	2	1	2	2
2 Slope position	2	7	4	3	8	8	3	3	2	8
3 Contour	2	2	4	1	2	4	2	2	4	2
4 Bedrock	4	3	3	3	3	3	3	3	3	3
5 Landform	10	4	7	7	7	7	7	7	7	7
6 Texture	6	n/a	3	4	5	1	4	5	3	5
Organic, in	5	n/a	6	4	4	7	5	7	4	7
Mineral, in	none	n/a	2	1	none	8	30	none	30	30
Volcanic ash, in	none	none	none	none	none	none	none	none	none	none
7 Soil moisture	6		7	7	4	6	6	3	6	3
Exp min soil, %	1		1	1	none	1	1	1	1	none
Litter, % cover	none		none	1	none	none	none	none	none	none
D/D wood, %*	1		none	none	none	none	none	none	none	none

**Dead and downed wood*

CODE DESCRIPTORS:

1 Likelihood of permafrost: near surface–1; probable–2; unlikely–3; none–4; unknown–5
2 Slope position: crest–1; upper–2; middle–3; lower–4; toe–5; stream bottom–6; bench/flat–7; depression–8
3 Land contour: convex–1; straight–2; concave–3; undulating–4
4 Bedrock type: igneous–1; metamorphic–2; sedimentary–3; none–4
5 Landform type: colluvial–1; Aeolian–2; floodplain (active)–3; floodplain (abandoned)–4; floodplain (other)–5; lowland "muck"–6; glacial–7; lacustrine–8; marine–9; organic–10; residual–11; manmade–12
6 Soil texture: gravel–1; sand–2; loam–3; silt–4; clay–5; organic–6
7 Soil moisture: peraquic–1; aquic–2; subaquic–3; perhumid–4; humid–5; subhumid–6; subxeric–7; xeric–8

SITES 61–68 Locations	Taylor9 61 Taylor Hwy 10.8	Taylor10 62 Taylor Hwy 9.4	Taylor11 63 Taylor Hwy 8.4	Taylor12 64 Taylor Hwy 7.4	Taylor13 65 Taylor Hwy 6.9	Taylor14 66 Taylor Hwy 6.5	DotLk2 67 AK Hwy 1370W	DotLk3 68 AK Hwy 1397S
Established	29-Jul-97	29-Jul-97	29-Jul-97	7//29/93	30-Jul-97	30-Jul-97	30-Jul-97	31-Jul-97
Altitude, ft	2710	2600	2300	2175	2050	2100	1500	1400
Aspect, deg	154	16	142	108	130	143	356	none
Slope, %	10	4	6	14	18	22	7	none
1 Permafrost	2	2	1	2	5	2	2	5
2 Slope position	4	3	3	3	8	3	3	8
3 Contour	2	2	4	2	2	4	4	2
4 Bedrock	3	3	3	3	3	3	3	3
5 Landform	7	7	7	7	7	7	7	7
6 Texture	1	5	5	2	3	2	4	4
Organic, in	5	7	8	9	7	10	6	5
Mineral, in	30	none	7	none	none	50	11	none
Volcanic ash, in	none	none	none	none	none	none	none	none
7 Soil moisture	4	3	3	4	5	6	6	5
Exp min soil, %	1	1	none	none	none	1	1	1
Litter, % cover	none	none	none	none	none	none	none	none
D/D wood, %*	none	none	none	none	none	none	none	none

**Dead and downed wood*

CODE DESCRIPTORS:

1 Likelihood of permafrost: near surface–1; probable–2; unlikely–3; none–4; unknown–5

2 Slope position: crest–1; upper–2; middle–3; lower–4; toe–5; stream bottom–6; bench/flat–7; depression–8

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4 Bedrock type: igneous–1; metamorphic–2; sedimentary–3; none–4

5 Landform type: colluvial–1; Aeolian–2; floodplain (active)–3; floodplain (abandoned)–4; floodplain (other)–5; lowland “muck”–6; glacial–7; lacustrine–8; marine–9; organic–10; residual–11; manmade–12

6 Soil texture: gravel–1; sand–2; loam–3; silt–4; clay–5; organic–6

7 Soil moisture: peraquic–1; aquic–2; subaquic–3; perhumid–4; humid–5; subhumid–6; subxeric–7; xeric–8

Appendix G. Stem Analysis Sites: Vascular Plants.

SITES 1–20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SHRUBS																				
ALNCRI					1		1				1		1				2		T	
ALNTEN														1	1				2	3
ARCRUB																		2		
ARCUVA			1	1								T					1			
BETGLA			1				1	2		4		1	2			1				
CASTET	1	1	1	1	1	1			2	2	1		4	1	1	2		2	2	4
JUNHOR	2		3	2	2	5	2	1	3	1	5	2	1	4	1	2	2	3		
LEDUM sp.														1						
OPLHOR			1	T			2	1						2	T			1		2
RIBTRI	1		1								T	1		T	1				T	
RUBARC								1		2	T	1								1
RUBPED	2		2	1			2	1	1	3	2	1	1	2	1		2	2	2	
SALIX sp.							1													
SALALA								1	1		1			1						
SALRET							T													
SORSCO											T	1	T				2			
SPIBEA			2	1		1	1	1	1	2	2	1	2	1	1	4	2	1	1	4
VACULI	2	3	2	2	1	1		1	1	1	4	1	1	2	1	2		1	6	
VACVIT															1					
GRASSES																				
CALCAN								2	1						1		2		6	
SEDGES																				
Eriophorum sp.								1			1									
HERBS																				
ACODEL				1																
ASTBOR																		T		
CASCAU	1										1		T		1		1			
DACARI	1																			
DRYINT		1									1	T								
EPIANG		1		T				1	5		1			4				1		
EQUARV							1	1							1			1		
EQUPRA	1																			1
EQUSCI							1			1	3	2	T							
EQUSYL															1					
GENPRO	1	2		1	2	2		1			1	1			1				2	4
GOOREP															1					
LINBOR				1										1					T	1
LUPARC	1	1	1					1	1		T				1				1	
MERPAN									1											
MOELAT																		1		
MONUNI											T									
PEDLAB								1			1							2	T	1
PETFRI		1								1										
PLAOBT				T							T									
POLACU															T					
POLALA	2	3	4		2						1	1		T						4
POTPAL										1									T	
PYRCHL					T															1
TRIEUR											T									

Cover classes are by percent, i.e., Trace=T (<1.0%); 1=1–5%; 2=5–25%; 3=25–50%; 4=50–75%; 5=75–95%; 6=95–100%

SITES 21–40	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
SHRUBS																				
ALNCRI		T		2	5	1	1									1				
ALNTEN		1																		
ARCUVA									1	4		2		T			2	1		
CASTET	3	1								1	1	T			1					
JUNHOR	2	4	1	4	3		1	1		1	2	2	2		T			1	4	3
OPLHOR	1	T																		
POTFRU					3															
RIBGLA															1	T		T		
RIBTRI		1	1		2	2		2			1				T	T				
RUBUS sp.									4	2		2								
RUBARC	1																			
RUBPED		2	2	2	1	2	1	T	2			1	T	T	1			1	1	
SALRET						3														
SHECAN											T									
SORSCO										2	1									
SPIBEA	3	T		1							1	1	1	T			1	2	2	
VACULI	3	4	2	4		4	4	1	3	3	3	2	3	4	1	2	2	1	1	2
VACVIT		T				2														
GRASSES																				
CALCAN			2	1	1				3	2					T		1			
unknown						2		1							T	2	1	T	T	
SEDGES																				
Eriophorum sp.	1			1																
HERBS																				
CASCAU				1				1			T		T	T	1				T	1
DRYINT			2				2				1		T			T	1			
EPIANG	T			2		2					T	1			1	1			T	
EQUARV		1	4		1	4		1		1								T		1
EQUPRA	T			1			1													
EQUSCI					5															
GENPRO	1	1	1		3	3		2			T		2	2				1	1	
GERERI					1															
HERLAN						4										T			T	
LUPARC		T			2	2	2									1				
PEDLAB	1	T																		
POLALA	T						2													
POTPAL						1														
PYRCHL						2									T					
SANCAN	1																			
STELON															1					
VERVIR						1														

Cover classes are by percent, i.e., Trace=T (<1.0%); 1=1–5%; 2=5–25%; 3=25–50%; 4=50–75%; 5=75–95%; 6=95–100%

SITES 41–60	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
SHRUBS																				
ALNCRI			2						1		1							1		
ARCRUB								2		1										
ARCUVA	1												1	1				1		
BETGLA				3	2	2	1													
CASTET	1	1		2				2	1	1			T	T	2	T	1			1
EMPNIG				1																
JUNHOR		1	1		4	2	2		2	1	1		1	T	1	1	1	1		1
OPLHOR										1										
RIBGLA																		T		
RIBTRI			1	1				1		T				1	1	1	1			
RUBUS sp.													1							
RUBARC	2				1	1			T		T							T		
RUBPED				1			1	T	1	1	T		1	1	1	1	1			1
SORSCO													T							
SPIBEA	2	T	1	3	1	3	3		1	2			1	1	2		1	2		2
VACULI	1	2	2	2	1	2	3	2	1	2	1		2	1		2	1	1		1
GRASSES																				
CALCAN														T	T	1	1	1		T
unknown	2	1											T							
Eriophorum sp.					1															
CASCAU		1	1											T		T	T			
EPIANG									T											
EQUARV	5														1					
EQUSCI			1																	
GENPRO		1											T	T		T	1			
LINBOR		2												T			T			
LUPARC		T	1							1			T	1		T				
POLALA	.			2			3													
Cover classes are by percent, i.e., Trace=T (<1.0%); 1=1–5%; 2=5–25%; 3=25–50%; 4=50–75%; 5=75–95%; 6=95–100%																				

SITES 61–68	61	62	63	64	65	66	67	68
SHRUBS								
ALNTEN							T	
ARCUVA	1	1						
CASTET	T		T	1	T	1	T	1
JUNHOR	1	1	1	1	1	1	1	T
RIBTRI			1	1	T	1	T	1
RUBARC	T		1				T	
RUBPED		2.0	1		1	1	1	1
SPIBEA	1	2.0		T				
VACULI	2.0		1	1	1	1	1	1
VACVIT					1	1	1	
GRASSES								
CALCAN	1	T	T	1	T	T	1	1
CASCAU						T	T	T
EPIANG							T	
EQUARV	1		T	T	T		T	
GENPRO				T	T	1	1	1
GOOREP							T	
LUPARC			T	T	1	T	1	
POTPAL			T					

Appendix H. Stem Analysis Sites: Trees and Non-Vascular Plants.

SITES 1–20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TREES																				
LARLAR							1	2			T									
PICGLA	2	2	2	1	1		3	3	1		1	1		3		1		1	2	
PICMAR	5	3	6	4	3	3	3	3	6	6	3	5	3	4	4	3	2	3	3	3
BETPAP	1			1	1		T				1	T		1			1			
POPBAL	1				1															
POPTRE		1															2			
REGENERATION																				
LARLAR							2	2												
PICGLA	1	2	1		1		1	2	4		T			2						
PICMAR	4	2	5	3	2	1	1	3		4	1	3	1	3	1	1	2	2	1	4
BETPAP				T	1						T						T			
POPBAL					1															
POPTRE																	1			
LICHENS																				
CETCUC																		T		1
CETNIV											1			1						
CLADINA sp.	3		1	1		1		1	4	1	1		4					5		2
CLAMIT																		T		2
CLARAN												T	2			T				
CLASTE					T								1			2		T		1
CLACHL							2													,5.
CLAECM																		T		
CLAUNC																1				
MASRIC						2							1							T
NEPEXP	1			1	1	1			1		1			1		1				
Peltigera sp.					1		2					T				1		T	1	T
PELAPH															1					
PELCAN																1				
PELNEO																				T
MOSSES																				
AULPAL																				5
CLIDEN																		T		
Drepanocladus sp.		1														T		2		
HEDCIL															5	1			6	
LYCANN																1	1			
PLADEN				2	3			3			5		2		1					1
PLESCH												1	2				2			
Polytrichum sp.					3	T	2									1				
RHYRUG			2						5											
SPHAG. sp.											2	3	2							
SPHCAP												3								
SPHFUS												3								
SPHGIR											2		2							
SPHSQU		3				6			1				2	1		2	4			
Tomenthypnum sp.	5																			
Cover classes are by percent; i.e., Trace=T (<1.0%); 1=1–5%; 2=5–25%; 3=25–50%; 4=50–75%; 5=75–95%; 6=95–100%																				

Appendix H. Stem Analysis Sites: Trees and Non-Vascular Plants.

SITES 1–20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TREES																				
LARLAR							1	2			T									
PICGLA	2	2	2	1	1		3	3	1		1	1		3		1		1	2	
PICMAR	5	3	6	4	3	3	3	3	6	6	3	5	3	4	4	3	2	3	3	3
BETPAP	1			1	1		T				1	T		1			1			
POPBAL	1				1															
POPTRE		1															2			
REGENERATION																				
LARLAR							2	2												
PICGLA	1	2	1		1		1	2	4		T			2						
PICMAR	4	2	5	3	2	1	1	3		4	1	3	1	3	1	1	2	2	1	4
BETPAP				T	1						T						T			
POPBAL					1															
POPTRE																	1			
LICHENS																				
CETCUC																		T		1
CETNIV											1			1						
CLADINA sp.	3		1	1		1		1	4	1	1		4					5		2
CLAMIT																		T		2
CLARAN												T	2			T				
CLASTE					T								1			2		T		1
CLACHL							2													,5.
CLAECM																		T		
CLAUNC																1				
MASRIC						2							1							T
NEPEXP	1			1	1	1			1		1			1		1				
Peltigera sp.					1		2					T				1		T	1	T
PELAPH															1					
PELCAN																1				
PELNEO																				T
MOSSES																				
AULPAL																				5
CLIDEN																		T		
Drepanocladus sp.		1														T		2		
HEDCIL															5	1			6	
LYCANN																1	1			
PLADEN				2	3			3			5		2		1					1
PLESCH												1	2				2			
Polytrichum sp.					3	T	2									1				
RHYRUG			2						5											
SPHAG. sp.											2	3	2							
SPHCAP												3								
SPHFUS												3								
SPHGIR											2		2							
SPHSQU		3				6			1				2	1		2	4			
Tomenthypnum sp.	5																			
Cover classes are by percent; i.e., Trace=**T** (<1.0%); **1**=1–5%; **2**=5–25%; **3**=25–50%; **4**=50–75%; **5**=75–95%; **6**=95–100%																				

SITES 21–40	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
TREES																				
LARLAR				2																
PICGLA	3	3		1	4	4		2			T				1	T				
PICMAR	2		1	3	2	3	3	3	4	3	4	3	4	4	4	4	4	4	4	4
BETPAP			2	3	3	1										2	T	T	T	
POPTRE																	T			
REGENERATION																				
LARLAR				3																
PICGLA	4	1		1		2		1								T				
PICMAR			1	4		2	3	1	3	2	2	1	2	2	1	1	1	1	2	1
BETPAP			1	2	1	1	1	T			T		T			T	T	T	T	2
POPTRE			1													T				
LICHENS																				
CETCUC	2			T																
CETDEL	3																			
CETNIV						1														
CLADINA sp.	3																			
CLAMIT	3																			
CLASTE				T			1													
Peltigera sp.				T		3														
PELAPH							2													
MOSSES																				
AULPAL	3																			
CLIDEN						1														
HEDCIL		5	4	5	5	4	4													
PLADEN	3					3	2													
Polytrichum sp.			2				2													
PTILIUM sp.							2													
SPHCAP	2																			
SPHGIR	2																			
SPHSQU		4																		
Tomenthypnum sp.								6	5	5	5	5	5	5	6	4	5	5	5	5
LIVERWORTS																				
LOPHOZIA sp.																T	T	T	T	T
Cover classes are by percent; i.e., Trace=**T** (<1.0%); **1**=1–5%; **2**=5–25%; **3**=25–50%; **4**=50–75%; **5**=75–95%; **6**=95–100%																				

SITES 41–60	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
TREES																				
LARLAR		T																		
PICGLA	1		1				1	1				2	1			1				
PICMAR	3	3	2	3	2	3	1	1	2	2		3	3	3	3	3	3	4	3	3
BETPAP		1	T						T	1		T	1		T	1				
REGENERATION																				
PICGLA	1							1				T	T			T				
PICMAR	2	1	T	1				1		1		2	1	3	2	2	2	1	2	1
BETPAP												T	1			1				
POPTRE	1																			
LICHENS																				
CETNIV					4	4	4	4	4	1	2									
CLAMIT				2	4															
STEPAS													1	4		2	1	1		1
MOSSES																				
RHYRUG			6			5	3	5	5	6	6									
Tomenthypnum sp.	5	5		5									3		5	4	3	3		3
LIVERWORTS																				
LOPHOZIA sp.																				T
Cover classes are by percent; i.e., Trace=**T** (<1.0%); **1**=1–5%; **2**=5–25%; **3**=25–50%; **4**=50–75%; **5**=75–95%; **6**=95–100%																				

SITES 61–68	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**
TREES								
PICGLA		T	1	2	1		1	
PICMAR	3	3	3	3	3	4	4	
BETPAP		T						
POPBAL			T					
POPTRE			T		1			
REGENERATION								
LARLAR								
PICGLA		T	1	1	1		1	
PICMAR	1	2	1	1	1	2	1	
POPTRE			T		1			
LICHENS								
STEPAS	1	1	1	4	2	2	2	1
MOSSES								
Tomenthypnum sp.	4	4	4		4	2	4	5
LIVERWORTS								
LOPHOZIA sp.	T	T	T			T	T	

Appendix I. Soil Pedon Descriptions at Selected Sites.

SMITH2 PSPs 406–408

Basic Information
Date sampled 09/26/2003
Soil series: Goldstream silt loam
Soil classification (tentative):
Coarse-silty, mixed, active, subgelic, Histic Aquorthel

Location Information
Soil Survey Area:
Fairbanks North Star Borough
Physiographic province:
Yukon-Tanana Lowlands
Latitude ....64°N
Longitude ....147°

Slope Characteristics
Slope 6%
Aspect ....214°
Horizontal shape ....slightly undulating
Vertical shape ....slightly convex

Physiography
Local physiography.......hills
Geomorphic position ....toeslope
Microtopography ....slightly hummocky
Parent material ....redeposited loess
Surface stones ....none

Soil Moisture
Flooding ....not reported
Moisture regime ....not reported
Permeability ....not reported
Drainage class ....poor
Runoff ....not reported
Type of erosion ....not reported

SMITH2 Pedon Description

O_i............0–12 cm; dark brown (10YR 3/6; 7.5YR2.5/3); peat; many very fine, fine, medium and few coarse roots; abrupt smooth boundary (10–20 cm)

O_e ....12–24 cm; black (10YR 2/1) peaty muck; many very fine, fine and common medium roots; many fine medium charcoal particles; clear smooth boundary (12–15 cm)

O_a ....24–37 cm; black (10YR 2/1); muck; moderate coarse platy structure; friable, nonsticky and nonplastic; many very fine and fine roots; many fine charcoal particles; pH 6.4; abrupt wavy boundary (10–18 cm)

B&A.......37–55 cm; dark olive brown (2.5Y3/3, 60%) silt loam and black (2.5Y2.5/1) mucky silt loam; weak medium platy structure; friable, slightly sticky and slightly plastic; many very fine and fine roots; abrupt wavy boundary (12–18 cm)

B_g .... 55–70 cm; very dark grayish brown (2.5Y 3/2, 40%), dark yellowish brown (10YR 4/4, 30%) and dark olive brown (2.5Y 3/3, 25%) silt loam with 5% black (10YR2/1) organic streaks; moderate thin platy structure; very friable; slightly sticky and slightly plastic; pH 6.6; abrupt smooth boundary (16–20 cm)

B_w/O_{aijf}.... 70–80 cm; olive brown (2.5Y 3/3, 70%) and black (10 YR 2/1, 30%) mucky silt loam; moderate very thin platy structure; frozen; slightly sticky and slightly plastic; abrupt smooth boundary

C_f............ 80–100 cm; olive brown (2.5Y 3/3) silt loam; strong very thin platy to lenticular structures (<1mm thick); extremely firm (frozen); slightly stick and slightly plastic; 45% ice as thin ice lenses

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CLEARY: PSPs 412–414

Basic Information
Date sampled................. 09/06/2003
Soil series...................... unnamed
Soil classification:
Loamy-skeletal, mixed, superactive, subgelic, Lithic Histiturbel

Location Information
Soil Survey Area:
Fairbanks North Star Borough
Physiographic province:
Yukon-Tanana Highlands
Latitude......................... 65° N
Longitude...................... 147° W

Slope Characteristics
Slope 6%
Aspect .... 128°
Horizontal shape .... slightly convex
Vertical shape .... slightly convex

Physiography
Local physiography....... mountains
Geomorphic position..... shoulder slope
Microtopography:
Gelifluction lobes, moss mounds
Parent material:
Colluvium and residuum (Birch Creek schist)
Surface stones 5%

Soil Moisture
Flooding .... not reported
Moisture regime .... not reported
Permeability .... not reported
Drainage class .... poor
Runoff .... negligible
Type of erosion .... none

CLEARY Pedon Description

O_i............ 0–10 cm; dark reddish brown (5YR3/3) peat (dead moss roots); many very fine, fine, common medium and few coarse roots; abrupt wavy boundary

O_a .... 10–17 cm; black (7.5YR 2.5/1) mucky silt loam; moderate fine granular structure; friable, slightly sticky and slightly plastic; common very fine, fine and medium roots; 5% gravel; abrupt smooth boundary

B_w1 .... 17–35 cm; dark yellowish brown (10YR4/4) sandy loam; 10%gravel; moderate medium subangular structure, very friable, slightly sticky and slightly plastic; few very fine, fine and medium roots; clear wavy boundary

B_w2 .... 35–68 cm; olive brown (2.5Y4/4) gravelly sandy loam, 17% gravel; moderate medium subangular structure, friable, slightly sticky and slightly plastic; few fine and medium roots; clear wavy boundary

C_r .... 68–80 cm; light olive brown (2.5Y 5/4) extremely channery loam; 75% channers and fine gravel (Birch Creek schist); friable, slightly sticky and slightly plastic

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9MILE: PSP 415–417

Basic Information
Date sampled................. 08/15/2002
Soil series...................... unnamed
Soil classification.......... unnamed

Location Information
Soil Survey Area........... not reported
Physiographic province:
Interior Alaska Highlands
Latitude .... 62° N
Longitude .... 142° W

Slope Characteristics
Slope 13%
Aspect 304%
Vertical shape .... plane
Horizontal shape .... undulating

Physiography
Local physiography....... hill backslope
Geomorphic position..... lower third of slope
Microtopography........... slightly undulating
Parent material .... not reported
Surface stones: .... not reported

Soil Moisture
Flooding .... not reported
Moisture regime .... not reported
Permeability .... not reported
Drainage class .... not reported
Runoff .... not reported
Type of erosion .... not reported

9MILE Pedon Description

O_i .... 0–11 cm; 7.5 YR 2.5/3 peat; many fine, many medium and few coarse roots; abrupt smooth boundary (5–12 cm)

O_e .... 11–18 cm; 5 YR 2.5/2 peaty muck; weak fine to medium granular structure; very friable; common charcoal particles; many fine and common medium roots; abrupt smooth boundary (2–7 cm)

E .... 18–22 cm; 10 YR 6/4 fine sandy loam; massive structure; friable, nonplastic and nonsticky; few fine and medium roots; charcoal particles common in upper part; oxidation concentration around fine root channels; abrupt wavy boundary (1–7 cm)

B_w .... 22–41 cm; 7.5 YR 3/3 silt loam; weak fine platy structure; friable, slightly plastic and slightly sticky; few fine and medium roots; abrupt smooth boundary

C2........... >41cm; 2.5 YR 3/3; gravelly loamy sand; single grained, nonplastic and nonsticky; no roots visible in unfrozen portion (soil frozen at ~43 cm); 17% fine pebbles

DUNE PSPs 430–432

Basic Information
Date sampled 09/23/01
Soil series......................not reported
Soil classification (tentative):
Sandy, mixed, active, frigid Vitriandic Cryopsaments

Location Information
Soil Survey Area:..........not reported
Physiographic province:
Interior Alaska Highlands
Latitude ....63°N
Longitude ....142°W

Slope characteristics
Slope 2%
Aspect ....0°
Horizontal shape ....convex
Vertical shape ....slightly convex

Physiography
Local physiography.......not reported
Geomorphic position.....plane
Microtopography...........sand dune
Parent material:
Volcanic ash over sand dune
Surface stones ....not reported

Soil Moisture
Flooding ....ponding
Moisture regime ....udic
Permeability:
Moderate in the solum;
rapid in the substratum
Drainage class ....excessive
Type of erosion ....not reported

DUNE Pedon Description

O_i1.......... 0–7 cm; brown (7.5YR 4/4) peat, mostly moss roots; many fine and medium roots; abrupt smooth boundary

O_i2.......... 7–10 cm; very dark grayish brown (10YR 3/2) peat; moderate fine platy structure; very friable, nonsticky and nonplastic; many fine, medium and few coarse roots; voids filled with sandy particles, likely blown from roadcuts; abrupt wavy boundary (3–7 cm)

A............. 10–19 cm; dark yellowish brown (10YR 4/4) very fine sandy loam; weak fine subangular blocky and weak medium granular structures; very friable, nonsticky and nonplastic; common fine, medium and few coarse roots; 30% charred organics and roots; abrupt irregular boundary (0–10 cm)

E............ 19– 27 cm; pale brown (10YR 6/3, 50%), gray (10YR 6/1, 30%) and light yellowish brown (5Y 4/1) loamy very fine sand; massive; very friable, nonsticky and nonplastic; common fine and few medium roots; 20% discontinuous pockets of charred organics and charcoal particles; abrupt irregular boundary (0–9 cm)

B_w........... 27–39 cm; brown (10YR 4/4) loamy fine sand; weak moderate subangular blocky structure; very friable, nonsticky and nonplastic; common fine roots; clear wavy boundary (12–16 cm)

C1 .... 39–49 cm; dark olive brown (25Y 3/3) sand; massive, slightly compact; very friable to loose, nonsticky and nonplastic; few very fine roots; clear smooth boundary

C2 .... 49–100 cm; very dark grayish brown (25Y 3/2) sand; single grained; loose, nonsticky and nonplastic; no roots

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TOWER1 PSPs 466–468

Basic Information
Date sampled 09/22/01
Soil series......................not reported
Soil classification:
Coarse–loamy, mixed, superactive, frigid nonacid Vitrandic Dystrocryept

Location Information
Soil Survey Area 176
Physiographic province:
Interior Alaska Highlands
Latitude ....63°N
Longitude ....141°W

Slope Characteristic Information
Slope 6%
Aspect ....90°
Horizontal shape ....slightly convex
Vertical shape ....plane

Physiography
Local physiography.......hills
Geomorphic position.....ridgetop
Microtopography...........nearly level
Parent material:
Volcanic ash over residuum/colluvium
Surface stones ....not reported

Soil Moisture
Flooding ....no ponding
Moisture regime ....udic
Permeability ....moderate
Drainage class ....moderately well
Runoff ....not reported
Type of erosion ....none

TOWER1 Pedon Description

O_i............0–10 cm; peat, mostly dead moss; many fine and common medium and few coarse roots; at the bottom of this horizon, a discontinuous pocket of charred organic layer 0.5–3 cm thick; abrupt smooth boundary

A.............10–13 cm; black (10YR 2/1) and grayish black (20YR 3/2) mucky fine sand; massive; very friable, nonsticky and nonplastic; many very fine and fine, common medium and few coarse roots; abrupt wavy boundary (3–10 cm)

E.............13–25 cm; light gray (10YR 7/1), pale brown (10YR 6/3, 30%) and yellowish brown (10YR5/4, 20%) very fine sand; weak thin platy structure; very friable, nonsticky and nonplastic; common fine root remains and medium to coarse charred roots; common fine, few medium and coarse roots; part of this horizon penetrating into the underlying horizon; abrupt irregular boundary (0–30 cm)

B_w...........25–35 cm; dark yellowish brown (10YR 4/4) gravelly sandy loam; weak fine subangular blocky structure; friable, slightly sticky and slightly plastic; many (35%) medium Fe depletions (25Y4/2) around root channels; common fine and few medium roots; 25% angular rock fragments; E horizon material occupying 35% of this horizon; clear smooth boundary (10–20 cm)

BC..........35–49 cm; brown (10YR 4/3) gravelly sandy loam; weak medium subangular blocky and weak medium reticular structures; friable, slightly sticky and slightly plastic; few fine roots; 30% rock fragment; clear smooth boundary

C1...........49–70 cm; brown (10YR 4/3) very gravelly sandy loam; weak medium subangular blocky structure; friable, slightly sticky and slightly plastic; common very fine root remains; common fine vesicular pores; 5% E pockets; 40% rock fragments; clear smooth boundary

C2 ....70–90 cm; very dark grayish brown (25Y 3/2) very gravelly sandy loam; moderate medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine root remains; many fine vesicular pores; 40% angular and sharp rock fragments; clear smooth boundary

C_r ....90+ cm; fractured schist bedrock

Appendix J. Sample Field Data Sheet.

SITE DESCRIPTION CREW::

DATE	LOCATION	TOWNSHIP	RANGE	SECTION	QTR-SECT
PLOT NO.					
REGION	AREA NAME				

ELEV (FT) ASPECT (°) SLOPE (%)	CIRCLE ANSWERS				
	PERMAFROST	CONTOUR	BEDROCK	POSITION	LANDFORM/SOIL
	near surface probable likely not	convex straight concave undulating	igneous metamorphic sedimentary none	crest upper slope mid slope toe slope	colluvial Aeolian floodplain (circle) active abandoned other lowland "muck" glacial lacustrine marine organic residual man-made

SOIL TEXTURE	SOIL DEPTH	SOIL MOISTURE	SOIL COLOR (MUNSELL)
gravel sand loam silt clay organic	O layer, in. _________ Min layer to bedrock, in. _________	peraquic aquic subaquic perhumid humid subhumid subxeric xeric	COMMENTS

TREES (>4.5')*	COVER CLASS*	SHRUBS	COVER CLASS	HERBS, GRASSES, BRYOPHYTES	COVER CLASS
LARLAR *Larix laricina*	/				
PICGLA *Picea glauca*	/				
PICMAR *Picea mariana*	/				
BETPAL *Betula papyrifera*	/				
POPBAL *Populus balsamifera*	/				
POPTRE *Populus tremuloides*	/				
POPTRI *Populus trichocarpa*	/				

***Rate trees (≥ 4") and regeneration (≤ 4") separately; i.e., 4/2.**

VEGETATION COVER CLASSES: **0** (absent) / **T** (T) / **1** (1–5%) / **2** (5–25%) / **3** (25–50%) / **4** (50–75%) / **5** (75–95%) / **6** (95–100%)